PRELIMINARY HISTORY
OF
NASA

1963 - 1968

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1968

CHAPTER IV

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SPACE SCIENCE AND APPLICATIONS*

1963 - 1968

INTRODUCTION**

Much of the heritage in aeronautics and space bequeathed to the new Administration when President Johnson assumed the reins was rooted in the new President's own efforts in establishing and supporting the national space program during the years immediately after Sputnik I. In space science and applications the first formulation of the U. S. space effort, embodied in the National Aeronautics and Space Act of 1958, set for the nation continuing goals. Not only did the Space Act call for a program to advance human knowledge of the atmosphere and space, and to make practical applications of space knowledge and technology, but the Act enjoined the newly created National Aeronautics and Space Administration to conduct the program in such a manner as to preserve U. S. leadership, cooperate internationally, coordinate and assist defense agencies, utilize national scientific and engineering resources effectively, and disseminate broadly the results of its research and development programs. An early objective, which was reinforced and elevated by the introduction of the Gemini and Apollo projects into the program during the Kennedy Administration, was the development of a broad national aerospace capability, with which to secure our freedom of choice as to our destiny in space, to enhance our world posture in science and technology, and to establish the basis

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*Material for this chapter was prepared by William R. Corliss.

**This introduction was written by Dr. Homer E. Newell for aerospace applications to practical uses. In keeping with this aim, NASA management shaped the space science and applications programs not merely as a loose collection of separate and important projects, but as an integrated effort to advance our science and technology broadly, including the use of men in space, to seek new discoveries, and to open important new frontiers. Nor was the agency content with a narrow definition of success in its undertakings, but rather sought to conduct its programs in such a way as to strengthen those institutions with which it worked: industry, universities, other government agencies, and the international scientific and technical community.

In the area of science the expressed intention was to seek out and attack problems of broad scope, particularly those likely to yield deeper insights into fundamental laws and the nature of the universe, and those problems involving a range of disciplines. NASA's intent was to support scientists not just in individual disconnected experiments, but over long enough periods of time that they might contribute to the development of new concepts and the reshaping of our views of the Earth, its atmosphere, and space. A critical objective in the evaluation of research proposals was, while advancing knowledge in important areas, also to lay the basis for further, even more penetrating advances across the frontiers of knowledge.

In the area of applications, while seeking to develop specific uses of aerospace knowledge and technology, NASA also sought to develop the basis for further more significant applications. NASA's role was that of conducting research and development; exploring new areas and means of aerospace applications. NASA carefully avoided taking on regulatory, administrative, or operational aspects of aerospace applications, undertaking instead to assist other users, particularly other government agencies, through agreed arrangements, to progress toward their goals through research and development and systems engineering.

Much of this effort came to fruition during the Johnson Administration. NASA's space programs have had a substantial impact on U. S. science and the U. S. scientific and technological posture in the eyes of the world. The space approach has strengthened and extended the geosciences in four significant ways: (i) by providing powerful new tools; (ii) by opening up new areas of geoscience; (iii) by extending geoscience to other planets; and (iv) by drawing geoscience, astronomy, and physics closer together. Using the rocket and specialized spacecraft, the scientist has been able to mount a powerful new attack in investigations of the Earth's high atmosphere and space environs. In the vicinity of the Earth, the magnetosphere has been discovered and investigated, and found to be fascinating, complex, and importantly involved in the processes by which the Sun influences the Earth. No longer is geoscience confined to the investigation of only one body of the solar system, the Earth. The Moon and other planets are now a real part of the claim-stake of this important discipline and their study will contribute, and indeed already has contributed, to illuminating the investigation of our own Earth. Thus, as a result of researches coming to fruition during the post five years, we are now in a position to enlarge our concept of the Earth's environment to encompass the entire solar system. With this perspective we will increase greatly our ability to penetrate the mysteries of our own planet, including those which will inevitably be involved in wrestling with problems of pollution of our environment, and the development and use of the Earth's resources. It is in this broadened concept of our planet's environment that the geosciences, astronomy, and physics come together, to the enrichment of all of them.

The physicist finds in outer space a gigantic new "laboratory" for conduct of fundamental researches on magnetohydrodynamics, collisionless shock waves, relativity, gravitation, and the fundamental nature of matter. Such a broad spectrum of research opportunities holds high promise of fundamental discovery.

Today astronomers wrestle with some of the most exciting and puzzling problems in the history of astronomical research. Radio galaxies, quasars, pulsars, celestial x-ray sources, all of them unexplained, appear to strike at the very roots of modern theory. Here again answers may well be of the most fundamental nature. It is clear that much of the information needed to understand these and other celestial phenomena is to be found in the infrared, ultraviolet, and x-ray wavelengths that cannot penetrate the Earth's atmosphere to observers on the ground. It is correspondingly clear, then, that spaceborne observations and experiments will have to share a large part of the burden of solving these known mysteries and other mysteries yet to appear. Indeed, the puzzling x-ray sources were first discovered in sounding rocket experiments, and many of these discoveries occurred during the past several years.

Finally in the area of bioscience, investigations of the behavior of terrestrial organisms under space conditions made in Biosatellite II launched in 1967, led to some startling results. It is now apparent that some terrestrial organisms behave differently under conditions of weightlessness in space. Thus the importance of space bioscience has been established, pointing the way toward further experiments in satellites and the ultimate search for extraterrestrial life on other planets of the solar system.

The space applications area presents a similar picture. As may be seen from the review of specific projects contained in the pages to follow, there have been substantial achievements in the development and use of weather, communications, and geodetic satellites. But important as these accomplishments are, greater value must in the long run attach to the basis which has been established over the past years for the development of even more significant practical applications of the future. We are now in the position to press forward with research and development leading toward a long-term weather forecasting capability, continuous weather surveillance from synchronous orbit, and the establishment of a suitable basis for experimenting with weather modification and control. It will be possible in the years ahead to develop a high-capacity, multiple-access, steerable, synchronous-orbit, direct-voice-and-TV-broadcast satellite system which can have a profound effect upon national and worldwide use of communications. The initial basis has been laid for development of civilian satellite navigation systems, satellite assistance to air traffic safety and control, and space observation and monitoring of Earth resources which will be important to the better development and use of the natural and cultural resources of our planet.

The true significance of the above is to be found in the NASA and other elements of our national aerospace capability, with their contribution to national scientific and technological strength. This capability contributes to our power and ability to choose, shape, and develop our role in the future world, assisting in aiding those who seek the betterment of conditions on this planet, and deterring those who would otherwise be inclined to take calculated risks for their own aggrandizement at the expense of others. This national capability, vigorously sought and worked for during the early years of the space program, coming into fruition during the Johnson period, affords now a real and expanded opportunity for further development of national strength and continued improvement of human welfare. It is in this context that the detailed history of the space science and applications events from 1963 to 1968 should be viewed.

THE SETTING

On November 26, 1963, four days after President Kennedy's assassination, NASA launched Explorer XVIII, its first Interplanetary Monitoring Platform (IMP). IMP I epitomized the posture of NASA's space science and applications programs at that critical moment in history; it was a highly successful scientific satellite built to explore the Earth's environs.

In late 1963, NASA's accomplishments in geophysics were recognized around the world. The Van Allen radiation belts, the Earth-encapsulating magnetosphere, and the solar wind had all been discovered in a span of just five years. The first Orbiting Solar Obsevatory (OSO) was already in orbit analyzing the Sun's radiation. Mariner II, NASA's 1962 Venus probe, had made man's first reconnaissance of another planet. In space applications, the Tiros, Syncom, and Relay satellites were revolutionizing weather forecasting and world-wide communications. In planning and development were the large geophysical and astronomical Observatories, more Mariners, the Surveyors, Biosatellite, the Nimbus weather satellite, and several other spacecraft. NASA's Office of Space Science and Applications (OSSA), resulting from the merger of Science and Applications Offices in the November 1, 1963, reorganization of Headquarters, was moving toward bigger and better space laboratories; spacecraft that would place scientific focus on the Moon and planets and reconnoiter the Moon for the Apollo program.[1]

To launch its spacecraft, OSSA had developed the reliable Delta and Scout rockets and had great hopes for its liquid-hydrogen Centaur stage for Atlas. Supporting its spacecraft in orbit and heading toward the Moon and planets were the Space Tracking and Data Acquisition Network (STADAN) and the Deep Space Network (DSN) run by the Office of Tracking and Data Acquisition (OTDA).[2] OTDA had deployed tracking and data acquisition stations around the world and had connected them with real-time communications circuits (NASCOM). STADAN was equipped to track, command, and acquire data from Explorer-class satellites as well as the soon-to-be-launched Observatory class spacecraft.[3] The JPL-operated DSN was able to track and communicate with lunar and planetary probes with its 85-foot-diameter paraboloidal antennas and had already established a long-distance communication record during the 1962 fly-by of Venus when Mariner II was 36 million miles from Earth.

In sum, NASA's spacecraft and their ground-support facilities provided an enviable inheritance for the new Johnson administration.

But what did science and the potential to do more science contribute to the real goal of NASA? Few deny that President Kennedy's decision to rapidly expand the space program in 1961 had political and strategic values.[4] Some relevant ingredients in Kennedy's decision were:

1. To pose a new challenge to the American nation.[5]

2. To create areas of new technology that would enhance America's economic and military position.[6]

3. To demonstrate high competence to the rest of the world and to collaborate with other nations in a program that was intrinsically peaceful and beneficial to mankind.

Although landing a man on the Moon was considered by many to be the primary challenge posed by President Kennedy in his May 25, 1961, message, the development of large boosters, large manned spacecraft, and unmanned spacecraft for the exploration of the Moon and planets were major elements of the total plan with merits of their own. During the early 1960's, newspapers habitually devoted front-page space to every Explorer launch--an event hardly noticed in 1968. Indeed, space science sustained public interest in space while the Apollo program was gestating, particularly during the long periods between the Mercury and Gemini and the Gemini and Apollo manned flights.

Space science is based on numerous technologies: rockets, remotely controlled machines, electronic miniaturization, radio communications, computer data processing, and above all, the trained people and sophisticated facilities that make it possible. Measured in these general terms, in November 1963, OSSA programs already had stimulated the aerospace industry, the electronics industry, and the computer industry to a considerable extent, but greater payoffs were still in the future.* And the NASA university programs managed by OSSA--aimed at developing a space-oriented cadre of new scientists--had begun to yield important results.

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*See Chapter VII.

Internationally, the U.S. space science and applications efforts had impressed the rest of the world, not only with results but with the openness of the programs and the freely available data. By 1963, England, Italy, Russia, France, and Canada were involved jointly with the U.S. on scientific and applications satellite programs. Other nations cooperated in sounding rocket experiments. The STADAN and DSN stations that ringed the world were ambassadors of good will par excellence. Foreign nationals staffed many of these stations and partook directly of the new technology.

From the scientific standpoint, there was a great deal for NASA to accomplish during the new Johnson Administration, for as Vannevar Bush had once said, science is "an endless frontier." Every new answer in geophysics had posed new questions to satellite experimenters; the Moon and the planets were pristine. Essentially, OSSA had two general objectives: (1) The extension of knowledge and understanding of the Earth, the Moon, the planets, the space environment and its effects on life, and (2) the application of space knowledge and technology to practical uses. The author of a statement of these general objectives, Homer E. Newell, then Associate Administrator for Space Science and Applications, followed them with this paragraph in testimony before Congress:

> In pursuing these objectives, we seek to maintain U.S. leadership in these important scientific and technological areas, to add to and strengthen the total scientific competence of our Nation, to cooperate to our mutual benefit with other countries, and to strengthen those universities and other institutions that work with us. . . .

OSSA PHILOSOPHY

The scientific community has for a decade been divided into opponents and proponents of space science. Nonsupporters have ranged from those who believe that space money could be better employed, say, in building more terrestrial telescopes, to sociologists who feel that physical scientists have received more than their fair share of Government money. To OSSA management, such criticism of their programs hurt, and OSSA worked hard to allay it.

A 1963 statement of Philip Abelson, editor of Science, set the mood of many space antagonists.[8] Abelson at that time was aginst the manned lunar program -- the "Moondoggle," as he called it -- and though he was warm toward OSSA unmanned science programs, he felt that the space program distorted scientific priorities and drained away vital manpower. Another tack was taken by Philip Morrison, then a Cornell professor, who claimed that money put into the Orbiting Astronomical Observatory (OAO) would be better spent on ground-based astronomy.[9] Many scientists generously supported NASA, but the critical -- especially those outside the physical sciences -- argued that enthusiasm seemed to be related to the amount received in NASA grants.

In spite of the disturbing criticism, OSSA management chose to work tirelessly to involve the scientific community directly in OSSA programs. Homer E. Newell recapitulated his philosophy in this way:

> The viability of our Space Science Program depends on the competence and quality of the scientists working with us. It is our conviction that NASA must have highly competent scientific groups within its Centers. At the same time, the majority of our space science effort is, and we believe it should be, carried out by scientists outside of NASA, primarily in the university community. We draw the scientific community into our program through the opportunities to do research on space missions. . . .[10]

Newell believed that the universities were the wellspring of new ideas and new scientists that OSSA had to tap.

OSSA management decided in the early 1960's to handle relations with the scientific community directly rather than delegate this to the Centers. The first object was to get individual scientists involved in OSSA programs as: (1) Experimenters on OSSA spacecraft; (2) members of OSSA's Space Science Steering Committee subcommittees; or (3) employees at Headquarters, the Centers, or the Goddard Institute for Space Studies. Another objective was the cultivation of the scientific community and the solicitation of advice through the Space Science Board of the National Academy of Sciences.

The Space Science Steering Committee and Mission Boards

The Space Science Steering Committee (SSSC) has been one of OSSA's vehicles for obtaining advice from the scientific community. The SSSC itself has always been composed exclusively of OSSA staff personnel. Each SSSC subcommittee, however, has consisted of the best scientists NASA could attract, although the subcommittee chairman is always an OSSA employee and a member of the SSSC. Subcommittees were established for Astronomy, Bioscience, Ionosphere and Radio Physics, Solar Physics, Particles and Fields, Planetology, and Planetary Atmospheres.

OSSA created the first of its Missions Boards in 1967. Like the SSSC subcommittees, the Mission Boards are composed of top scientists; however, the chairmen are non-NASA scientists.[12] The members are free of detailed, routine decision-making and have the assignment to help NASA set strategy and map out long-range plans for the exploration of space.

The SSSC subcommittees and the Mission Boards not only provide OSSA with valuable advice, but they also have been key instruments in educating and involving the scientific community in OSSA programs.[13] The SSSC subcommittee structure has been responsive to the changing OSSA mission. New subcommittees added since 1964 include: Communications, Earth

Resources, Geodesy and Cartography, Meteorology, Navigation, Planetary Biology, and Space Biology. Many of the new titles reflect OSSA's increasing emphasis on space applications.

The Space Science Board (SSB)

The SSB is an advisory arm requested by NASA which was established in 1958 within the National Academy of Sciences; its specific concern is the national space program. Until 1964, both NASA and the National Science Foundation supported the SSB. From that date on, NASA has been its sole support.[14]

The NASA-SSB link has been strong and effective, perhaps NASA's strongest association with the scientific community. SSB interlocks with NASA decision-making machinery in that at least one SSB member sits on each SSSC subcommittee and each Mission Board. Although NASA cannot fund all SSB-recommended programs, NASA science and applications programs show strong SSB influence. And, of course, SSB is a vital communication channel with the scientific community.

OSSA-SSB symbiosis was already well established when the Johnson Administration commenced. During the next five years, SSB annually reviewed OSSA programs,[15] but its best known accomplishments were its more definitive summer studies, such as the one held at Woods Hole in 1965,[16] which surveyed the whole NASA science program.

Like its predecessor report, A Review of Space Research,[17] the 1965 Space Research; Directions for the Future became a basic reference document for OSSA planners. Again, however, the side benefits have proven useful to NASA. The summer sessions permit NASA and the scientific community to sit down together and think out space-research strategy, using a common language and common ground-rules.[18]

The Universities

NASA's Sustaining University Program has provided another link to the scientific community.[19] There have been three parts to the Program:

1. Training, which increases the supply of scientists and engineers.

2. Facilities, which provide new laboratory space.

3. Research funds, which enable universities to support NASA space science.

All three categories strengthen both the universities themselves and NASA programs as well. Although some legislators may feel this is the equivalent of an aid-to-education program,[20] Congress has funded the program, cutting back only in recent years.[21] In his Fiscal 1968 testimony before Congress, Homer E. Newell stated:

> Because of the important challenges of space science, over 200 colleges and universities have involved themselves with space research. The major fraction of our space science research is carried out in these institutions. At present, approximately 1500 faculty members and over 2000 graduate students are actively engaged in space science and technology. In addition, under NASA sponsorship, there are at present some 3600 students now studying for doctoral degrees by working on space-related problems in some 30 academic disciplines.

OSSA's Rangers, Lunar Orbiters, and Surveyors, despite their high scientific payoffs, were supported primarily as being essential to the Apollo manned lunar--landing--a national goal. Toward the end of the period, such science projects as the Voyager planetary program fell as budget constraints were imposed by the Vietnam war and other priority national programs. Satellites were beginning to be seen not only as scientific instrument carriers but also as tools for helping to solve practical human problems, such as environment control and the discovery of new terrestrial resources. Space science was still an important NASA objective in 1968, but it was beginning to share the stage with new applications born from the earlier scientific efforts.

Recently it has been generally recognized that the space program is a rich source of new technology. A key OSSA technical objective has been the construction of complex automated spacecraft. Although science and applications motivate the construction of these spacecraft, they are technical accomplishments of a high order that enhance the general technological competence of the nation. From the Explorer-class satellites to the big Observatory spacecraft, with their hundreds of thousands of parts, OSSA spacecraft are helping build that man-machine world Landers calls the "dybosphere."[22] As we shall see, it was OSSA's engineering confrontation with the Observatory-class spacecraft that created many of the problems the organization faced in the 1963-1968 period.

The OTDA world-wide networks, which support OSSA missions, are also great technical accomplishments. These networks, connected together by real-time communications lines and associated data-processing facilities, constitute one of the largest data-handling machines in the world.

The following historical treatment of space science and applications programs is divided into four parts: (1) space science, (2) space applications, (3) launch vehicles, and (4) tracking and data acquisition.[23]

Space Science

Continuing the taxonomy, OSSA divides its scientific programs into four groups: (1) Space physics and astronomy,

(2) lunar and planetary exploration, (3) manned flight experiments, and (4) bioscience. Before discussing these areas, it is useful to show how the tools of space science have developed.

The essence of space research is the projection of scientific instruments from the surface of the Earth either into the environment under study (say, the ionosphere) or into a more advantageous position, say, satellite orbit around the moon, where the absorbing and distorting effects of the Earth's atmosphere are not so serious. OSSA employs five different classes of vehicles as instrument carriers: High-altitude aircraft, balloons, sounding rockets, satellites, and deep-space probes. Each of these classes has its own development hisory and its own use history.

Space Physics. The tools of space physics consist of all vehicles mentioned above. OSSA carries out about fifty balloon flights each year and logs about 100 hours per year in high-altitude aircraft. Sounding rocket flights number about 100 yearly. These three types of vehicles are used mainly for exploring the atmosphere and ionosphere.

Most of the 20 Explorer-class satellites launched during the past five years have carried space physics instrumentation.[24] In the 1958-1963 time frame, the Explorers concentrated on the elucidation of the Van Allen radiation belts, the magnetoshere, and the ionosphere. During the past five years, attention has shifted more to the Earth's atmosphere, the boundary region between the magnetosphere and the interplanetary milieu, and Earth-Sun relationships. The IMP series of Explorers is perhaps typical of the 1963-1968 era, during which six of these small but very reliable and effective spacecraft were launched. The IMP's carry magnetometers, radiation detectors, and other instruments around the Earth in highly eccentric orbits or, in the case of the Anchored IMP's, around the Moon. Other types of Explorers launched during this period were Direct Measurements Explorers, Beacon Explorers, Aeronomy Explorers, and the Geodetic Explorers Geos and Pageos.[25] The only Explorer failure during the past five years was Beacon Explorer A, which failed to attain orbit on March 19, 1964 due to a launch-vehicle failure.

The most difficult-to-develop research vehicle employed in space physics has been the OGO. The large OGO's (about 1100 pounds) carry twenty or more instruments;the scientific objective being the simultaneous measurement of many geophysical parameters. From the engineering standpoint, OGO's provide experimenters with fairly standardized vehicle environments to simplify instrument integration. The result is a complex spacecraft.

Four OGO's were orbited successfully between 1964 and 1968. OGO I (September 5, 1964) has been called a "successful failure." After orbit had been attained, two spacecraft booms failed to deploy properly, preventing spacecraft stabilization with respect to the Earth. At this point, the value of a big spacecraft with redundant equipment and diagnostic instrumentation was evident. Project engineers were able to determine the trouble and dispatch commands that put OGO I in a spin-stabilized mode of operation. The satellite then returned a wealth of data. The failure initiated a review of the OGO program, resulting in some design changes. OGO II was orbited on October 14, 1965. Again stabilization was a problem; this time the horizon scanners tracked false horizons, so in a few days the supply of attitude-control gas was exhausted. Using the lessons learned from OGO's I and II, OGO's III and IV have proven very successful.

OSSA's aircraft, balloons, sounding rockets, and spacecraft have revealed a complex environment surrounding the Earth, an environment that is continually stirred by solar activity. The Van Allen belt, the magnetosphere, the Earth's dust cloud, and other geophysical phenomena were discovered prior to November 1963. More recent scientific efforts have been in the direction of filling in the many details; that is, thorough mapping of the radiation zones, the ionosphere, and atmosphere as a function of time. Major mysteries remain; we still do not know the source of the particles that create the auroras and the airglow.[26] The magnetosphere is still a major target. Spacecraft, such as the IMP's, have discovered that the Earth possesses a long magnetospheric tail pointing away from the Sun; this tail extends beyond the Moon, which on occasion passes through it.

To investigate the interplanetary medium and the solar disturbances that course through it, OSSA and Ames Research Center developed the Pioneer probes.[27] Ames issued a proposal request in January 1963, and in June 1963 chose Hughes Aircraft Corporation to build four spacecraft. Three of the new Pioneers have been successfully launched into orbits around the Sun during the 1965-1968 time frame. They have helped chart the solar wind, solar plasma tongues, and the interplanetary magnetic field.

Solar Physics. The objectives of solar physics are: (1) The understanding of the Sun's constitution and behavior, and (2) the understanding of the physical processes by which the Sun affects the Earth. To accomplish these objectives, OSSA has at its disposal the same research vehicles it uses for space physics. Rockets, satellites, and space probes all carry instruments above the Earth's atmosphere, where they can view the Sun's ultraviolet and X-radiation as well as the solar particulate radiation.

Many early solar physics experiments were carried out using balloons and sounding rockets. Several Explorers and OGO's have included solar physics instruments in their inventories. One Solar Explorer (Explorer XXX), built by the Naval Research Laboratory and launched by NASA, was launched in 1965 to monitor the Sun during the International Year of the Quiet Sun (IQSY). The OSO's, though, have been NASA's major vehicle for solar instruments. The fortunes of the AOSO and the Sunblazer probe are also of historical interest.

OSO is a small Observatory, weighing roughly 500 pounds. It is characterized by a "sail" kept pointed at the Sun and a spinning "wheel" section. Instruments are mounted in both sections. The first of the series, launched March 7, 1962, sent back a great volume of solar data. However, on April 14, 1964, the second OSO was destroyed during checkout at Cape Kennedy when the third-stage solid-propellant X-248 rocket motor ignited.[28] An investigation following the accident blamed static electricity for the explosion. OSO-B2, a reconditioned prototype was orbited as OSO II on February 3, 1965. OSO III was successfully launched in 1966. Both have been valuable spacecraft.

The OSO's have performed well, but OSSA wished to have a spacecraft with an order of magnitude increase in solar resolution for the 1968-1969 solar maximum. Following studies in 1961, three $100,000 study contracts were let to industry in late 1962. In November 1963, NASA let a $5 million contract to Republic Aviation Corporation for the development of the Advanced Orbiting Solar Observatory (AOSO). On December 16, 1965, after the expenditure of $39 million, AOSO was cancelled.[29] In the Fiscal Year 1967 Hearings, NASA testified that the cancellation could be attributed to budgetary constraints and the higher priority of other OSSA programs.[30] Eventually, many AOSO developments were carried over to the Apollo Telescope Mount (ATM) program.

Data from OSO's and other spacecraft have given solar physicists an opportunity to refine their models of the solar atmosphere.[31] Continuous observation of the Sun has also provided a means for predicting solar flares.

Space Astronomy. In space astronomy, as in solar physics, the goal of the space scientists is to place instruments well above the Earth's atmosphere. In contrast to the easily located Sun, the stars are many and hard to find for an automated spacecraft. The difficulty in finding stellar targets and stabilizing on them has made NASA's OAO a major engineering challenge. Before looking into the OAO program, it should be noted that a large amount of space astronomy can be accomplished with sounding rockets and Explorer-class spacecraft. Extensive stellar surveys, however, require a large, precision-pointing Observatory.

Conceived along with the OGO in the early days of NASA as a second-generation scientific satellite, the OAO proved to be a rather large technological bite. The design study contract for OAO was let to Grumman Aircraft Corporation on November 30, 1960. The real complexity of the spacecraft plus some major development problems came to light during the first year's work. All told, the OAO complexity, star tracker intransigence, and the sheer size of the computer control program (some 300,000 instuctions) combined to produce a delay of approximately two years in the launch of OAO I.[32]

On April 8, 1966, OAO I was placed in orbit, but on its second day its power supply failed. The failure was attributed to arcing in the star trackers and a breakdown in the Battery Charger and Sequence Controller. Here again, even in failure, positive results were achieved. In the few hours power was available, the stabilization subsystem, the communication, and various other equipments were proven out.

Following OAO I, review boards were set up at Headquarters and Goddard. Some 129 recommendations were specified in the Headquarters Review Board Report. In OSSA's Recovery Plan, 103 of these were implemented. Of the 103, 71 recommendations involved spacecraft design changes; 17 others suggested changes in program management.[33] Another OAO launch is scheduled for late 1968.

While the first OAO's will observe in the ultraviolet region of the spectrum, the Radio Astronomy Explorer (RAE) detects low frequency radio waves emanating from sources in and outside the galaxy, radio frequencies that cannot penetrate the Earth's ionosphere. The RAE is an Explorer-class satellite with four deployable 750-foot antennas. The first conceptual designs of the RAE were carried out at Goddard in 1963. Later the spacecraft construction contract was awarded to Fairchild-Hiller.[34] On July 4, 1968, RAE I was placed in orbit by a Delta rocket, and it has operated perfectly, extending its antennas completely and mapping the sky at radio frequencies.

Prior to RAE I and OAO I, sounding rockets launched by NASA and the Naval Research Laboratory had provided almost all the data for space astronomy. Two of the most important results from sounding rocket flights are: (1) Stars are brighter than expected in ultraviolet light, and (2) there are many strong X-ray sources in the galaxy. Such discoveries have made the OAO more important than ever to astronomers.

Lunar and Planetary Exploration

The Moon and planets have always been major astronautical targets. By late 1963, four programs had entered the development cycle; Ranger, Lunar Orbiter, and Surveyor focused on the Moon, while Mariner's targets were the planets Venus and Mars. All of NASA's 1963 lunar and planetary programs except Lunar Orbiter were managed by JPL; Lunar Orbiter was at Langley. In 1963, the only success that NASA could claim was the 1962 flyby of Venus by Mariner II. Ranger and Surveyor had encountered hardware and management problems, and Lunar Orbiter was just getting underway. Yet during the next five years, OSSA's Planetary Programs Directorate, combined with JPL and Langley to turn every program mentioned into a success story.

The Moon. The major scientific objectives of lunar exploration are: (1) Determine the Moon's structure and its internal processes, (2) analyze surface composition, geologic structures and processes, (3) sketch out the origin and evolutionary history of the Moon, and (4) use the data to better understand the history of the solar system. The Apollo manned lunar landing program added two practical questions: (1) Can men land on the Moon and return safely, and (2) where are the best landing sites?

Several types of unmanned, automated lunar missions were envisaged by NASA and JPL in 1959 and 1960. A spacecraft could fly by the Moon, impact its surface in a "hard" landing, go into orbit around it, softland on its surface, or even land and then return to Earth. In order of increasing difficulty, the three selected were Ranger (hard landing), Lunar Orbiter, and Surveyor (soft landing).

Ranger. The Ranger program was started formally at JPL in December 1959, well before Apollo became a national objective. Science was the major objective at that time; specifically, early close-up photos of the Moon and data that would be obtained from instruments, such as seismometer, which would survive impact. The first two of the Rangers (Block I) were actually engineering flights in Earth orbit, while three Block II Rangers were lunar hard landers. None of the first five Ranger missions succeeded.[35]

After the failure of Ranger V, the program was scrutinized in late 1962 by a special review board. This board recommended a postponement of the next Ranger launch and the prior completion of a design review and new test program. In addition, an industrial company -- Northrop Corporation -- was brought in to assist JPL in certain areas. The Ranger program was also modified as a result of President Kennedy's May 1961 announcement of the manned lunar landing effort. Ranger was studied to see how it might aid the expanding

Apollo program. As a result, Ranger Block III was authorized, and six high resolution TV cameras were included in each spacecraft to provide close-up views of the lunar surface. In July 1963, NASA cancelled the more sophisticated Block IV Rangers. Finally, on December 13, 1963, NASA also cancelled the five spacecraft in Block V because of funding problems. Homer E. Newell announced that NASA would place more reliance on the Block III Rangers, Surveyor, and the new Lunar Orbiters.[36]

Despite program consolidation and the tightening of JPL management, Ranger faced one more tragedy. On January 30, 1964, Ranger VI left for the Moon with everything apparently functioning perfectly. At about 1300 miles from the lunar surface, Ranger VI was supposed to begin taking pictures, but no pictures were received back at Earth.

Concern in Congress and NASA arose to new heights after Ranger VI. A common question was: How can we send a spacecraft to Venus but fail four times with the Moon? In early February, a new Board of Inquiry was established by NASA Administrator Webb. Two review groups at JPL also inquired into the cause of failure. Later, four days of hearings were held by the House Subcommittee on NASA Oversight.[37] The most likely cause of Ranger VI's TV silence was an inadvertent turn on of the camera while the rocket was ascending through the Earth's atmosphere, an event that probably led to arcing in the equipment and its subsequent failure at the Moon.

During the next six months, major changes were made in circuitry design and hardware. The next Ranger underwent a more thorough testing and checkout regimen. The design fixes and the test program were sufficient, because on July 28, 1964, Ranger VII was launched toward the Moon and completed its mission three days later without flaw. Rangers VIII and IX repeated the Ranger VII success on February 17, 1965, and March 21, 1965.

The thousands of Ranger pictures showed countless lunar craters of all sizes. The pictures taken just before impact resolved details less than two feet apart. The smaller craters seemed to have a "windblown" appearance, indicating some erosion process. Small craters were not distributed uniformly; many seemed to be secondary craters located in the bright rays of larger craters. The photos showed few rocks and little rubble, although crevasses and slumping were noted. Ranger IX returned excellent views of the crater Alphonsus, some showing craters inside surrounded by dark, ash-like debris that might have been ejected by subterranean activity. In sum, the Ranger pictures gave scientists a better look at the lunar surface than centuries of telescope gazing.[38]

Lunar Orbiter. The Lunar Orbiter program began at JPL in 1958 and 1959, when scientists and engineers were trying to synthesize a comprehensive lunar program.[39] In the early 1960's, an orbiter was conceived as a version of the Surveyor soft lander (called the Surveyor Orbiter). Meanwhile, NASA Headquarters became concerned that JPL, then struggling with Ranger, Surveyor, and Mariner, might be overburdened by Surveyor Orbiter. Eventually, Headquarters decided that the project should be assigned to Langley Research Center. On August 30, 1963, Robert C. Seamans, Jr., signed the Project Approval Document and Lunar Orbiter officially began.[40]

Langley issued a request for proposals for Lunar Orbiter on August 29, 1963. On December 20, 1963, Boeing Company was selected for negotiation. Obviously Lunar Orbiter was moving rapidly as projects go. At this point, it should be noted that OSSA originally favored a spinning Lunar Orbiter that operated much like wheel-type Tiros satellites. Boeing, however, proposed a stabilized spacecraft and convinced NASA management on this approach.[41] On May 8, 1964, Boeing and NASA signed an incentive contract for some $80 million for five spacecraft.

Lunar Orbiter, a second-generation spacecraft, has been one of NASA's most successful projects. Cost increases and schedule delays were relatively minor. All five spacecraft were launched and completed their lunar missions during 1966 and 1967.[42]

The hundreds of Lunar Orbiter pictures extended the views taken by Ranger to the entire lunar surface. Craters were abundant, with population densities varying from 1700 per square mile down to 250. Such nonrandomness could stem from volcanic action or from ejecta from large primary craters.[43]

The rough lunar uplands have two to three times fewer craters than the dark maria. Parallel ridges and troughs are also seen in the uplands. This distinctly different character of the uplands led to the dispatch of the last Surveyor to that region.

Another important discovery of Lunar Orbiter was a small population of fresh craters. These craters are sharp and distinct, with angular blocks prominent on their floors and external slopes. The existence of fresh craters alongside seemingly weathered craters indicates that some sort of erosion continues on the Moon. In addition, some craters show evidence of material flow or "mass wasting."

In its Apollo support role, Lunar Orbiter helped certify five landing sites.

Surveyor. Surveyor's genesis, like those of Ranger and Lunar Orbiter, took place in the 1960 period. NASA Headquarters formally approved the Surveyor project in the spring of 1960. Surveyor also preceded President Kennedy's call for a manned lunar landing; thus, the initial objectives were mainly scientific in charcter. The early Surveyor craft were supposed to carry 200 pounds of instruments, including TV, seismometers, X-ray spectrometers, gas chromatographs, and a variety of other equipment to diagnose the lunar surface.[44] With Apollo expanding, the prime mission of Surveyor was to assure that astronauts could land safely on the Moon.

After numerous studies, including four in industry, Hughes Aircraft Company received a letter contract for Surveyor on March 1, 1961. The original Hughes contract for seven flights was for $67 million. The total program cost was estimated at $125 million in the original Project Development Plan. By November 1963, the beginning of the period covered by this history, Surveyor was in deep trouble. (See also the later discussion of the Centaur launch vehicle stage.) Major difficulties had been encountered with the engineering design of this revolutionary, automated soft-landing spacecraft. Costs had climbed and schedules had slipped badly.[45] As the Subcommittee on NASA Oversight admitted, some changes were expected in a program as difficult as Surveyor, but the Subcommittee considered those of Surveyor to be excessive. By 1965, Surveyor had slipped 2 1/2 years, and the estimated total cost had tripled.

The Surveyor technical problems centered around the vernier engine, the main retrorocket, and the Radar Altimeter and Doppler Velocity Sensor (RADVS).[46]

A Headquarters project review was carried out at JPL and Hughes from March 23 through 27, 1964. The April Review Report recommended that JPL establish a stronger, projectized organization and assign more JPL personnel to monitor Hughes.[47]

The upshot of the soul searching was a major reorganization of JPL. The Surveyor project staff rose from about 100 to 500 within a few months. Hughes came under intensive surveillance by JPL. Naturally, some strain in the JPL-Hughes relationship developed with this sudden attention by JPL. One outcome was a series of contract negotiations and changes to provide more disciplined conduct of the project.

The House Committee on NASA Oversight came to several conclusions in their 1965 report:

1. NASA did not do sufficient groundwork for Surveyor at the project's beginning.

2. NASA Headquarters should have exerted firm control over JPL sooner than it did.

3. JPL concentrated on Ranger and Mariner while essentially turning Surveyor over to Hughes.

4. Hughes top management did not pay enough attention to Surveyor.

On May 30, 1966, when Surveyor I left Cape Kennedy, all systems performed well. In view of past difficulties, it was a pleasant surprise when Surveyor I braked to a successful soft landing on the Moon and began to send back pictures of the lunar landscape. Of the seven Surveyor shots from 1966 through 1968, only Surveyors II and IV failed to land successfully and return data. On later Surveyors, sampling arms and alpha-scattering experiments (for composition determination) were included. There were also touch-down dynamics experiments to test the strength of the lunar crust.[48, 49]

The Surveyor series revealed that the lunar surface will assuredly support astronauts. The surface layer seems much like damp sand and contains some rocky debris both on and below the surface. Perhaps the chief scientific discovery of the Surveyors was made by the alpha-scattering experiment. Surveyors V and VI revealed that the mare surface material has a composition much like that of terrestrial basalt. However, the rough lunar uplands, as diagnosed by Surveyor VII, has a different composition. This fact indicates that some differentiation of the lunar surface has occurred during geologic time.

The Planets

OSSA planetary missions have suffered severely from budget restrictions. Yet public and scientific curiosity about the planets is high. One can make a good case for OSSA's plans for flights to Mars and Venus.[50] Historically, NASA's planetary program has consisted of two major projects: Mariner and Voyager. There have been three successful Mariner flyby missions, but Voyager was cancelled before it really got started. The three Mariner flights, however, have greatly altered our scientific images of Mars and Venus.

The Mariner program began at JPL in the 1959-1960 period along with Ranger and Surveyor. In view of the hardware and managerial troubles with its sister projects, the superbly executed Mariner II flyby of Venus in 1962 was astonishing. As the Johnson Administration began, two Mariner spacecraft were being prepared for a flyby of Mars in 1964.[51] Plans also existed for Mariner shots during the Mars 1966 and Mars/Venus 1969 firing windows.[52] A small ejectable instrument capsule was being studied for the 1966 Mars mission. At this point in time, the Voyager orbiter-lander program was only in the thinking stage, with shots contempleted for the 1969 window.

Mariner III was launched from Cape Kennedy on November 5, 1964. Its launch shroud failed to eject and the craft was scientifically useless. Mariner IV departed for Mars on November 28, 1964, and flew past the planet at a distance of 6200 miles on July 14, 1965. To date, Mariner IV has been the world's only successful Mars probe.

Twenty-one pictures from Mariner IV's camera revealed a planet pock-marked with craters much like the Moon's. Although a few scientists had predicted Martian craters, the scientific world was generally surprised by their profusion. Some linear geological features on Mars seem associated with the famous canals seen by some astronomers over the years. Other spacecraft instruments found that Mars has no significant magnetic field and no radiation belts. The Martian atmosphere is thin and is thought to be composed mostly of carbon dioxide and argon.[53]

In the spring of 1965, the more ambitious Voyager program was picking up speed. OSSA conceived of Voyager as its second-generation planetary program and began to concentrate its efforts and resources on it rather than Mariner. Mariner Mars 1966 was dropped as a result.[54]

During Fiscal Year 1966, however, funds for planetary exploration began to get tighter. The first Voyager flight was delayed until 1973, leaving several firing windows without U.S. probes. Some Voyager money was reprogrammed to Mariner to take full advantage of these natural opportunities. It was too late to resurrect the Mars 1966 program, but one Mariner spacecraft was assigned to the 1967 Venus window and two to the 1969 Mars window.

The Mariner V probe was a rebuilt spacecraft left over from Mars 1964 shot. It was launched successfully and flew past Venus on October 19, 1967. Instruments on Mariner V found Venus to be without any significant magnetic field. The planet does possess an ionosphere that deflects the solar wind. The atmosphere of Venus is apparently very hot -- about 500^{o}F -- and about 80 percent carbon dioxide.[55]

With the complete cancellation of Voyager in Fiscal Year 1968, OSSA's Mariner program was the only planetary effort left. To augment the two Mariner 1969 shots planned for Mars, OSSA proposed additional flights to Mars in the Fiscal Year 1969 hearings.[56] The 1971 spacecraft would be a Mars orbiter and the 1973 mission would include both an orbiter and a lander.

Since 1965, the fortunes of Mariner and Voyager have been closely related. When Voyager slowed down, Mariner picked up speed, and vice versa. Let us now take a closer look at Voyager -- OSSA's second-generation planetary probe.

Voyager studies began in 1961 at NASA Headquarters and JPL. On April 8, 1963, NASA selected AVCO Corporation and General Electric Company to study the technical feasibility of Voyager, which was then conceived as a large orbiter-lander combination, like the Lunar Orbiter-Surveyor combination in principle. In December 1964, OSSA decided upon a program calling for a Voyager Mars mission in 1971. JPL was selected as the project manager. A request for proposals was issued by JPL on January 19, 1965. On April 22, 1965, General Electric, Boeing and Thompson-Ramo-Wooldridge's Space Technology Laboratories were each awarded three-month, $500,000 contracts to make preliminary design studies. By the end of 1965, Voyager was moving toward hardware development, although this decision had not yet been made.

The Voyager mission was predicated upon a large spacecraft, two of which would be launched at the same time by a Saturn V launch vehicle. The Mars entry capsule would weigh between 5000 and 7000 pounds. By early 1966, however, the first Voyager shot had slipped to 1973 as funds became more difficult to find for planetary studies.

OSSA worked hard to sustain Voyager momentum. The scientific community, too, was much more enthusiastic about Voyager than Apollo. This attitude is evident in the following quotation from the 1965 SSB study:[57]

> The biological exploration of Mars is a scientific undertaking of the greatest validity and significance. Its realization will be a milestone in the history of human achievement. Its importance and the consequences for biology justify the highest priority among all scientific objectives in space -- indeed, in the space program as a whole.

By 1966, other elements of NASA had been brought into the management picture:

OSSA	Program director.
JPL	Surface laboratory, tracking and data acquisition, and operations.
Langley	Entry capsule and landing system.
Marshall	Orbiter development and retro-propulsion, Saturn V.

Voyager was now anticipated to be a multibillion dollar program, to continue the momentum built up by Apollo.[58]

The Voyager program was cancelled before it became a large-scale development program despite all efforts to save it.[59] Shrinking funds in Fiscal Year 1968 were a major consideration, but some in Congress were also afraid that Voyager was only a "foot in the door" for a much more expensive manned planetary program. Nor could NASA prove the immediate worth of Voyager in practical terms that would appeal in a time of troubles at home and abroad.[60] Thus, by the end of 1967, the only approved planetary program was Mariner Mars 1969. It seemed that the U.S. had indeed abandoned the planets to the Soviet Union.

Manned Space Science

Until now this history has dealt with unmanned scientific spacecraft exclusively. The Mercury, Gemini, and Apollo programs, however, offered the opportunity for astronauts to carry out experiments directly. There has been great debate about the utility of scientist-astronauts. Proponents of manned space science claim that man is useful because of his adaptability, judgment, creativity, and manipulatory capability.[61] Experimental results from the Mercury and Gemini programs have helped dispel some of the reservations about astronauts as scientists.[62] In fact, scientists have now been chosen as astronauts to carry out lunar experimental programs.

Obviously, the history of manned space science overlaps that of manned space flight.* As originally established in 1964, the Office of Manned Space Science reported jointly to OSSA and OMSF (Office of Manned Space Flight). OSSA was involved because many of the scientific objectives were identical to those of its unmanned science programs, such as airglow measurements, astronomy, bioscience, and Earth observations. In addition, NASA management believed it wise to centralize all contacts with the scientific community in a single office, OSSA.[63]

The objectives of manned space science are to better understand the space environment and lunar conditions for: (1) The purposes of pure science; (2) support of manned space flight; i.e., meteoroid measurements; and (3) practical applications, such as those of the Earth resources program (described later). To accomplish these objectives, the Gemini spacecraft were available in the 1965-1966 period** and Apollo vehicles beginning about 1969.[64] Two important scientific projects are part of the forthcoming Apollo Applications Program (AAP): The Apollo Telescope Mount (ATM) and the Apollo Lunar Surface Experiment Package (ALSEP).[65] OSSA is involved primarily as "science manager."[66]

<u>Bioscience</u>

Bioscience is complex and multifaceted; it lacks the unity of the physical sciences. Space bioscience inherits this diffusiveness; this is one of the reasons why it has developed slowly. Another factor in the slow growth of space bioscience has been the fact that NASA began with a cadre of physical scientists and engineers. And, when space bioscience began to be recognized as a potentially fruitful area of space research, the bioscientists themselves responded slowly to these opportunities; perhaps because of the new techniques and machines involved in space research. With the OSSA Biosatellite series and a better appreciation of space research tools, space bioscience is now moving ahead rapidly.

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*See Chapter III.

**Excellent results from the Gemini experiments are described in Chapter III.

In OSSA, "bioscience" is managed by the Bioscience Programs Directorate under Orr W. Reynolds. The Office of Advanced Research and Technology (OART) is concerned with "biotechnology and human resources"; "space medicine" is the province of the Office of Manned Space Flight (OMSF). Here, we deal only with OSSA's bioscience.

OSSA bioscience has two primary objectives: (1) The detection and understanding of extraterrestrial life, and (2) the determination of the effects of the space environment on terrestrial species.[67] During the period covered by this history, the only space vehicle specifically devoted to bioscience has been Biosatellite. In terms of life detection and the sterilization of planetary spacecraft, a great deal of work has already been carried out here on Earth.[68]

In early 1962, NASA and the Air Force developed plans for a joint biological satellite.[69] In July 1962, however, the DOD and NASA agreed that the project should be wholly NASA's. NASA's Biosatellite was conceived as a recoverable, multi-experiment satellite -- NASA's first unmanned recoverable satellite. Biosatellite was officially approved on September 10, 1962, and project management was assigned to Ames Research Center. On March 1, 1963, Ames requested proposals for six-week study contracts. General Electric, Lockheed Missiles and Space Company, and Northrop Corporation won parallel study contracts. On August 21, 1963, NASA announced that General Electric had been selected to build Biosatellite.[70] A total of six satellites were planned; two each for three, 21, and 30-day missions.

Biosatellite I was successfully launched on December 14, 1966, with thirteen experiments. But after its successful performance during its three allotted days, its retrorocket failed to fire and recovery was impossible. As a result of the post-flight review, the retrorocket firing circuits were modified and several other changes made.[71] Biosatellite II was launched on September 7, 1967, and its capsule was successfully recovered after 45 hours in orbit.[72]

Space Applications

The practical applications of spacecraft have been recognized as well as their scientific potential.[73] Although communication and weather satellites were factored into the U. S. space program at an early date (Relay, Tiros, etc.), only recently have other applications been recognized. Earth resource satellites, for example, are relatively new.

A significant feature common to most OSSA applications programs is their research and development slant. Instead of trying to become the operator of satellite systems, NASA, like its predecessor agency, NACA, has assumed a role wherein it develops technology, and then passes it on to other operating agencies and/or industry. In satellite communications and meteorology, NASA has laid the groundwork for the operational systems of Communications Satellite Corporation and the Environmental Science Services Administration (ESSA). NASA still develops new instruments and techniques for both organizations. Instead of flying small, single-purpose R&D satellites, such as Syncom and Tiros, NASA now orbits larger, general-purpose R&D spacecraft, such as Nimbus and the Applications Technology Satellite (ATS).

It seems appropriate to close this introductory section with a quotation that underlines the great expectations that the U. S. now has for its space applications programs:

> The potential economic benefits to our society from space systems are enormous. They may amount to billions of dollars per year to many diverse elements of our industry and commerce and thus to the public. In some areas, it is possible to predict these benefits with accuracy; in others we can estimate within broad but conservative limits.[74]

Communication Satellites. NASA has developed three series of R & D communication satellites; Echo, Relay and Syncom. The histories of all three are closely linked together as well as with the DOD Courier, Advent, and West Ford projects.[75] Between 1956 and 1963, both NASA and DOD were searching for the best kind of communication satellite system. There were many options; communication satellites could be either passive or active, or at low, medium, and high altitudes. The debates were extensive and sometimes acrimonious, because cost factors were elusive and the whole technology was in its infancy.

NASA's Echo balloon satellite project predates NASA itself, as do many applications programs. Originally proposed by William J. O'Sullivan of NACA's Langley Aeronautical

Laboratory as an atmospheric research tool for the IGY, Echo's potential as a passive radio reflector was quickly realized. In 1959, Echo I became NASA's first communication satellite. Two successful launches occurred on August 12, 1960 and January 25, 1964. Although the large balloons were satisfactory radio reflectors, the Echo concept did not progress farther because a system of as many as 50 low orbit balloons would be required for good geographical coverage. Launch and ground station operation costs would have been high.

In August 1960, NASA began looking at low- and medium-altitude active communication satellites.[76] AT&T worked in this effort by building two Telstar satellites, which NASA launched for AT&T on a reimbursable basis. NASA's own active communication satellite was the medium-altitude Relay satellite. NASA did not begin work on a synchronous satellite at this time because DOD was already pursuing the idea as part of its Project Advent.

On the sidelines, Hughes Aircraft Corporation was an enthusiastic proponent of the synchronous communication satellite. Indeed, Hughes was trying to promote the concept with anyone who would listen. In particular, Hughes hoped NASA would begin a synchronous satellite program as an alternative to flagging Advent. With Hughes' urging support from within NASA from such managers as Leonard Jaffe, and the general expansion of the space program, the Syncom program finally came into being.

Meanwhile, NASA had awarded its Relay contract to RCA on May 18, 1961. Two Relays were launched; one on December 13, 1962, the other on January 21, 1964. The Relays (also the two AT&T Telstars) demonstrated that long-lived medium altitude communication satellites were indeed feasible. In the long run, though, a system of Relay-like satellites would have required many more spacecraft and a more complex ground station network than a system consisting of a handful of synchronous satellites. In short,it appeared as if a synchronous satellite system would be more economical if it could be made to work.[78]

It is curious that Syncom, one of NASA's greatest contributions in space applications, had such a difficult birth. The Syncom beginning was slowed first by the fact that DOD was already designing a synchronous satellite under Project Advent. In addition, there were serious technical doubts that a satellite could be launched into and then maintained in a synchronous orbit. Very precise control and an on-board propulsion system would be needed. But Hughes and NASA's Jaffe believed success was possible and persisted in their efforts to get NASA to build a Syncom. Finally, on July 27, 1961, Abe Silverstein, Director of Flight Programs at Headquarters, gave the go-ahead and assigned Syncom to Goddard. On August 11, 1961, NASA officially announced that Hughes had been selected to build Syncom.

Syncom I was launched February 14, 1963 and reached a near-synchronous orbit. Unfortunately, contact with the satellite was lost when the injection motor fired, and the satellite has since remained silent. Syncom II was successfully placed in a synchronous orbit on July 26, 1963. The final satellite in the series, Syncom III, was also successful. On August 19, 1964, Syncom III became the world's first stationary satellite; that is, it was maneuvered into a synchronous equatorial orbit and appeared to stay fixed above one spot on Earth. This feature made it easy for ground station antennas to acquire and lock onto the satellite. Many communications experiments were carried out with the two working Syncoms. The 1964 Olympic Games were relayed live from Japan. Together they proved the feasibility of long-lived synchronous communication satellites. Perhaps the best gauge of Syncom success is that the Comsat Corporation Early Bird and Intelsat communication satellites are direct descendants of Syncom.[78]

With the formation of Communications Satellite Corporation (Comsat Corp.), NASA's part in communication satellite technology reverted to its originally intended R & D role. Under the Communications Satellite Act of 1962, NASA acts in a support role to Comsat Corp. NASA's main tasks are the provision of R & D and launch vehicles with appropriate ground support, the later on a reimbursable basis.[79] OSSA now carries out general communications research on the ATS satellites (discussed later). Typical communications experiments have been in the areas of mechanically and electrically despun antennas, multiple access communication, and radio propagation.[80]

Meteorological Satellites. NASA's role in satellite meteorology has been similar to the part it played in developing operational communication satellites. NASA's small R&D satellites have been Tiros and Nimbus. The last two Tiros satellites (Tiros IX and X) were also used as prototype operational craft for the ESSA-funded Tiros Operational Satellite (TOS) System. In addition, NASA launches many meteorological sounding rockets each year. Once it had developed a suitable operational prototype, NASA turned operational responsibility for weather satellites over to ESSA and continued its R & D role in the Nimbus program.

The Tiros program had its origin in the contracts RCA held with the Army and ARPA in the 1956-1959 period.[81] NASA formally took over the Tiros program on April 13, 1959. Tiros was assigned to Goddard and, because of all the preparatory work was able to move ahead very rapidly. On April 1, 1960, Tiros I was sent into orbit -- the first of a string of 10 consecutive successful Tiros weather satellites.[82]

Each Tiros satellite has returned tens of thousands of cloud cover pictures and infrared data, giving meteorologists a panorama of the world's weather that they never had before. The Tiros data have helped improve weather forecasting, in particular the tracking of hurricanes and dangerous storms.

During the 1963-1968 period covered by this history, NASA introduced several important technical features on its Tiros series. On Tiros VIII, launched December 21, 1963, the first Automatic Picture Transmission (APT) equipment, (Developed under the Nimbus program) was flown, giving anyone possessing inexpensive receiving equipment an opportunity to receive cloud cover pictures of his immediate locality. Tiros IX (January 22, 1965) employed a new "wheel" configuration, enabling more pictures to be taken. Tiros X (July 2, 1965) demonstrated the feasibility of placing spacecraft in Sun-synchronous orbits that improve picture-taking conditions.

The Tiros series plus Nimbus sensor technology laid the foundation for the TOS (Tiros Operational Satellite) program, which led to the creation of an operational weather satellite system funded and managed by ESSA (ESSA calls its Tiros-derived satellites ESSA's).[83] Originally NASA had hoped that its second-generation R&D weather satellite, Nimbus, started in 1959, would be the basis of the nation's operational meteorological satellite system. NASA's relationship with the Weather Bureau (now part of ESSA) is too complicated and lengthy to report here.[84] Summarizing briefly, on September 27, 1963, the Weather Bureau announced that it was withdrawing its support of the Nimbus Operational Program (NOS), begun in 1961, primarily because Nimbus appeared to be too costly as the basis for an operational system. Behind the public statement, however, was also the fact that the NASA-Weather Bureau working relationship had apparently not been entirely satisfactory to the Weather Bureau,[85] mainly because of inherent divergences between research and operational goals.

The Nimbus program began in the spring of 1959 with studies at Goddard and Headquarters.[86] General Electric was put under contract to integrate and test the spacecraft on February 15, 1961. When the Weather Bureau withdrew from the program (along with its share of the funds), the Nimbus program no longer seemed so essential to Congress. NASA now decided to continue Nimbus as an R & D vehicle on which it would test out new sensors and techniques to support satellite applications technology.[87] Nevertheless, Nimbus funds were reduced significantly in Fiscal Year 1965.

The Nimbus program continued with the following objectives: (1) Testing new flight sensors, (2) measuring the vertical structure of the atmosphere on a global basis, and (3) providing for global collection of in-situ meteorological data.

Nimbus I was launched on August 28, 1964. It was a generally successful flight except that a failure resulted in a 26-day life that was disappointingly short. Better resolution cloud cover pictures were obtained, and some new weather satellite instruments were tested, in particular a High Resolution Infrared Radiometer (HRIR). On May 15, 1966, Nimbus II was launched. This spacecraft carried more advanced experiments and was far more successful than Nimbus I, continuing to operate after more than two years. On this flight, a Medium Resolution Infrared Radiometer (MRIR) and an Advanced Video Camera System (AVCS) were added to the APT and HRIR equipment. The AVCS takes TV pictures of the Earth and its cloud cover with a resolution of about a half mile.[88]

The only failure in the entire NASA weather satellite program occurred on May 18, 1968, when the Nimbus-B launch vehicle failed to place the spacecraft in orbit. NASA intends to launch the same payload on another Nimbus in 1969. Three additional spacecraft have been approved beyond the 1969 launch.

Although the Nimbus program was once clouded because it seemed to have no immediate application after the Weather Bureau's action, the program recently received strong endorsement during the 1967 Summer Study Group of the National Academy of Sciences.[89] The Group estimated that one-to-two week weather forecasts are ultimately possible and that the potential benefits to the U.S. alone are about $1 billion per year, and recommended the Nimbus as an excellent spacecraft for developmental platform for second and third generation instruments.

The ATS. The Applications Technology Satellite or ATS (originally called the Advanced Technological Satellite) was an outgrowth of a 1962 Advanced Syncom Study project at Hughes Aircraft Corporation, When Comsat Corp. was created, NASA decided to reorient the Advanced Syncom program away from communications R & D and develop a satellite that could carry experiments in several areas of technology. The Hughes Advanced Syncom thus led to the ATS.[90]

In 1964 the ATS objectives were stated as:

1. Investigate and flight-test technology common to a number of satellite applications

2. Investigate and flight-test technology for the stationary orbit.

3. Conduct a carefully instrumented gravity-gradient orientation experiment.

4. Flight-test experiments for a number of types of satellite applications on each individual spacecraft.[91]

On March 2, 1964, NASA announced that it would negotiate with Hughes for the construction of five ATS spacecraft. With the addition of the ATS to the space applications satellite inventory, OSSA began the policy of soliciting applications-oriented experiments for flight. This approach had proved very successful on the scientific satellites. Originally, the first ATS (ATS-A) was scheduled to be launched in 1966. It was to be placed in a 6000-mile orbit and carry a three-axis gravity-gradient experiment requested by DOD. By early 1966, it became apparent that ATS -B, destined for a synchronous orbit, was going to be ready for launch before ATS-A. Consequently, it was ATS-B that became ATS I on December 6, 1966. ATS I carried several scientific and communication experiments and cooperated in the Weather Data Relay Experiment (WEFAX). The most spectacular results from ATS I came from its spin-scan camera, which provided many superb pictures of the Earth and its cloud cover from its high stationary orbit. ATS II (ATS-A, finally) went into orbit April 5, 1967, but its orbit was so highly elliptical (due to an Agena failure) that the gravity-gradient experiment could not be operated. ATS III was launched on November 5, 1967, into a stationary orbit. Its experiments included a mechanically despun antenna, a multi-color spin-scan camera, an ionosphere propagation experiment, a resistojet test, and several other experiments. The results from ATS I and III have proven very useful to communications and meteorology.[92]

Earth Resources

The potential benefits from Earth resources satellites seem limited only by one's imagination. By virtue of a satellite's vantage point and with the multitude of new sensors now being developed, the following are some of the practical applications that now appear possible in principle, although considerable R & D will be necessary:

1. Aid map preparation
2. Take crop censuses
3. Detect forest fires
4. Reconnoiter for minerals
5. Make air pollution surveys
6. Reconnoiter sea ice
7. Locate hydrothermal energy sources

The Departments of Agriculture, Interior, and Commerce are working with NASA to determine the utility of Earth resources satellites.[93]

The original OSSA Earth Resources Satellite Program grew out of its own meteorological satellites and the manned space flight programs. Weather satellite pictures and infrared data plus the excellent photos taken by Gemini astronauts together showed a wealth of useful facts. It was apparent that a great deal more useful information could come from a carefully planned long-term Earth resources program. Field operations in the Program are now managed at several centers, including the Manned Spacecraft Center and Goddard.

The objectives of the Earth Resources Technology Satellite Program include identification of areas of application and the development of better sensors.[94] Much of the initial R & D is to be carried out on general purpose satellites, such as the ATS and Nimbus. Several specific Earth resources satellites have already been proposed, both for R & D and for operational use. One of the first was the Earth Resources Observation Satellite (EROS) proposed by the Department of the Interior in 1966.[95] NASA's first satellite concepts were called Earth Resources Satellites (ERS). These were conceived as small spacecraft carrying imaging sensors in low altitude, Sun-synchronous orbits. ERS studies were carried out at Goddard in 1967. As the NASA concept became more refined, its name was changed officially to the Earth Resources Technology Satellite (ERTS) program. The name change is significant because it emphasizes NASA's anticipated R & D rather than operational role. The ERTS satellites are only in the study phase at present. Allied with the spacecraft studies is a sensor development and test program. Much of the sensor testing is carried out using aircraft over known areas.[96]

Other Applications Areas. In addition to the program areas described above, NASA's space applications program included geodesy, navigation, traffic control, and worldwide data relay.

Geodesy was one of the first sciences to use satellite data. NASA has launched the Pageos and Geos satellites to help geodesists tie the Earth's geodetic grids together with high accuracy. In 1962, NASA was chosen to be the lead agency in the National Geodetic Satellite Program. DOD and the Department of Commerce are also involved.[97]

The use of satellites as navigational aids is also as old as the space program. The only operational use to date has been by the Navy with its system of Transit satellites. For several years NASA has studied navigation satellites and, more recently, air traffic control. No flight programs have been approved.

In conclusion, two valuable byproducts of NASA's space applications should be mentioned. The first is the program's integrative force within the Federal Government created by applications that cut across agency lines. For example, NASA actively works with about twenty other U. S. Government organizations. The second byproduct involves cooperation with foreign countries. Many foreign governments have worked with NASA for years on space science projects; they are following suit on space applications. Weather prediction and communications are even more valuable to many countries than space science -- at least in the short run -- so it is not surprising to see dozens of countries interested in communication and weather satellites and the services they provide.[98]

Launch Vehicles

In addition to its many satellite projects, OSSA also has program management responsibilities for several launch vehicles. The OSSA launch vehicles are the Delta, Scout, Centaur, and the Air Force-derived Agena -- all rockets or rocket stages used primarily in launching satellites and space probes. The Saturn rockets and the nuclear rocket are managed elsewhere in NASA. On occasion, OSSA provides its rockets to other agencies and other countries.

All of OSSA's launch vehicles have historical origins before the November 1963 date stipulated for this account. Except for the Centaur and evolutionary improvements of the other launch vehicles, the development histories were essentially complete by 1963.

Delta. The highly successful Delta launch vehicle was based on the Thor-Able II rocket, which in turn owes much to the Vanguard rocket. NASA signed the first Delta contract with Douglas Aircraft Corporation on April 29, 1959. Following a failure to launch an Echo on its debut on May 13, 1960, the Delta became famous for its reliability record. For example, after the first launch there was an unbroken string of 22 successful launches, punctuated finally by the Beacon Explorer failure on March 19, 1964.

Beginning in 1964, some important imporvements were made on Delta. First, the X-25B upper-stage motor replaced the X-248. NASA also ordered an uprating of the Delta by increasing the size of the second stage; the result was called the Improved Delta. 1964 also saw the first use of the Thrust Augmented Delta, which employed three first-stage strap-on solid propellant rockets. All of these improvements were incorporated on the Thrust-Augmented Improved Delta or TAID. In 1968, the TE 364 upper-stage replaced the X-258, and the first stage Thor booster tanks were enlarged. In 1968 the Delta vehicle surpassed its previous mark of 22 consecutive successful launches and, as of July 30, 1968, has 24 consecutive successful launches.

Scout. The smallest of OSSA's launch vehicles, the solid-fuel Scout, has been used extensively during the 1963-1968 period, in support of NASA, Department of Defense, and International Cooperative Satellite launchings.

Centaur. The Centaur stage had its origin in a 1957 proposal submitted to the Air Force by General Dynamics/ Astronautics.[99]

The program was formally initiated in August of 1958 under the management of the Advanced Research Projects Agency (ARPA) of the DOD. The objectives of the program at that time were to demonstrate the feasibility of employing a liquid hydrogen/liquid oxygen propulsion system in space. Six test flights were planned. Approximately one year later, the program was transferred to the newly formed NASA. The project management remained with the USAF under NASA Headquarters overall management control.

In early 1960, the DOD ADVENT synchronous altitude communications satellite mission was assigned to Centaur, creating the requirement for some basic systems changes. In order to accomplish this mission, three-burn, restart, and six-hour-coast capabilities were required. Shortly thereafter project management was assigned to the Marshall Space Flight Center and the flight test program was increased to 10 flights. The impact of a mission requirement for restart and synchronous injection dictated that a number of features be incorporated into the program including pumps to be added to the propulsion system. On May 8, 1962, the first launch ended in a failure. The program was then transferred to the Lewis Research Center, in light of the overriding commitment of the Marshall Space Flight Center to the higher priority Saturn in the Manned Flight Program. This transfer was accomplished on October 1, 1962. The program was restructured and new priorities assigned. It was decided to focus on obtaining a single-burn capability to support the Surveyor Mission at the earliest possible date. Only after this had been achieved was a second burn capability to be considered. As a result, the third burn requirement was dropped, the coast-time design requirement was reduced to 25 minutes. The flight test program was reduced to eight shots in recognition of a shift in emphasis to ground testing. Atlas-Centaur (AC-2) was successfully launched in November of 1963. AC-3, launched in June of 1964, was a partial success. AC-4 launched in December of 1964 was completely successful, while AC-5, launched on March 2, 1965, failed. During this launch, the Atlas booster engines shut down and allowed the vehicle to fall back on the pad. In September of 1965, the AC-6 was successfully launched in the final qualification flight of the single-burn capability. This completed the initial phase of the Centaur Development Program.

The program continued with the launch of AC-8 in April of 1966. This was one of the two remaining vehicles allotted for qualification of the second-burn capability. This flight must be rated as a failure since it did not achieve the primary objective of completing the second burn. However, the failure was in no way related to the restart cycle.

In November of 1966, the AC-9 was successfully launched on a two-burn ascent mission with a Surveyor mass model on top. Since the completion of the development program, Centaur system has proven highly successful. The operational program included seven flights through July 1968.

Agena. The Air Force-developed Lockheed Agena was first used by NASA August 23, 1961, when the first Ranger was launched. Since then, NASA has often used both the B and D versions of the Agena in conjunction with the Atlas, Thor, and Thrust-Augmented-Thor booster stages. Typical spacecraft launched using the Agena have been OGO, Mariner, Ranger, Lunar Orbiter, Nimbus, ISIS X, and the Gemini Target vehicle.

As with Centaur, Agena management responsibility was shifted to Lewis Research Center. Until 1964, NASA purchased Agenas, as modified for NASA missions, directly from the Air Force. Beginning in 1964, NASA bought just the basic Agena stage and had the modifications made under NASA contract.

OTDA Support for OSSA

The Office of Tracking and Data Acquisition (OTDA) supports OSSA with two of its own networks; STADAN (Space Tracking and Data Acquisition Network) and the DSN (Deep Space Network); and contracts with the Smithsonian Astrophysical Observatory for the support of its network of Baker-Nunn cameras.[100] Together these networks provide the following services for OSSA: (1) Tracking, (2) acquisition of telemetry data, and (3) the dispatch of commands to the spacecraft. Intrinsic to such worldwide data support is OTDA's NASCOM, a global, real-time, terrestrial communication network. The OTDA networks are absolutely essential to the effective operation of any space science or application program. In addition to the great advances in tracking and communication technology pioneered by OTDA, its networks represent, in effect, U. S. ambassadors in many foreign countries.[101]

STADAN. STADAN grew out of the Naval Research Laboratory Minitrack interferometer network that was set up during the 1956-1958 period for tracking the Vanguard satellite during the International Geophysical Year.[102] During the early 1960's, the Minitrack stations were augmented by the addition of 85-foot and 40-foot data-acquisition antennas at various sites. These big dishes are needed to cope with the high data rates characteristic of the Observatory-class satellites. The first of the 85-foot antennas was installed at the Alaska STADAN station in 1962, where it was needed to acquire data from polar-orbiting Observatories, such as OGO II. By 1965, the primary purpose of STADAN had changed from tracking to data acquisition. Another major addition to STADAN has been range-and-range-rate tracking equipment, which is essential for the accurate tracking of spacecraft in highly elliptical orbits, synchronous orbits, and on trajectories to the Moon. Most range-and-range-rate equipment was installed during 1964 and 1965. The addition and phasing out of related STADAN stations during the 1963-1968 time period is summarized briefly below.[103] In general, OTDA has phased out its smaller sites in favor of fewer, better instrumented stations, such as Rosman, N. C., and Alaska.

In November 1963, STADAN consisted of stations at the following locations: Blossom Point, Maryland; Ft. Myers, Florida; Rosman, North Carolina; East Grand Forks, Minnesota; Mojave, California; College, Alaska; Fairbanks, Alaska; St. John's, Newfoundland; Winkfield, England; Johannesburg, South Africa; Quito, Ecuador; Lima, Peru; Santiago, Chile; and Woomera, Australia.

In 1964, a transportable station was installed at Majunga, Madagascar, to monitor the injection phases of satellites. Further requirements of manned space flights and of scientific satellites indicated the need for a permanent station. Therefore, the Tananarive, Madagascar, station was constructed. Tracking and telemetry operations began in April 1965.

During November, 1965, a new station in the Orroral Valley near Canberra, Australia, became operational. This station provided increased operational capability. The Woomera station operations were moved to the new location in July 1966.

The East Grand Forks station was closed in July 1966. Increased capability at Rosman and Fairbanks eliminated the necessity for East Grand Forks operations. In August, 1966, The Blossom Point operations were terminated. Test and training operations conducted here were transferred to the network test and training facilities at Goddard Space Flight Center. The next consolidation occurred in November 1966 when the College, Alaska, station was closed and operations moved to Fairbanks.

In November, 1966, the Toowoomba, Australia, station became operational to provide support for the ATS program.

The DSN. When JPL was transferred to NASA in 1959, it had already tracked the early Explorer satellites using its three-station Microlock network. In 1958, construction began on the first 85-foot antenna at JPL's Goldstone site in the Mojave desert. The early U. S. Moon probes, such as the early Rangers, were tracked by the Goldstone antenna, smaller antennas in various localities, and the Jodrell Bank radio telescope in England. Prior to 1963, JPL erected 85-foot antennas at Johannesburg, South Africa, and Woomera, Australia, which allowed it to track lunar and planetary probes on a continuous basis. JPL applied the name Deep Space Instrumentation Facility (DSIF) to this complex of stations. Using various leased circuits, JPL tied the DSIF stations to a control center at Pasadena called the Space Flight Operations Facility (SFOF). NASA calls the DSIF-SFOF combination the Deep Space Network (DSN).

In November, 1963, the DSN consisted of four 85-foot operational antenna stations, two located at Goldstone, California; one each at Woomera, Australia, and Johannesburg, South Africa. There was also a spacecraft monitoring facility at Cape Canaveral, a mobile station at Goldstone, California, and the SFOF control center at JPL Pasadena, California. Construction was underway on the Canberra, Australia, 85-foot antenna station and the Goldstone 210-foot antenna.

In 1964 another 85-foot station was started near Madrid, Spain. The Canberra and the Madrid stations became operational in 1965 and supported Mariner IV. During this time period, the operation of the Space Flight Operations Facility (SFOF) was transferred to OTDA from OSSA. In 1966, the Ascension Island 30-foot antenna station became operational. This station provided near-Earth support for lunar and planetary flight missions.

The DSN now had six 85-foot antenna stations (two subnets of three stations each) -- one subnet for the Launch Orbiter and Pioneer missions; the other for the Surveyor and Centaur launch vehicle development. The Mars 210-foot antenna station at Goldstone was also in limited use. All stations were operating at S-Band frequencies.

During 1967 the second Madrid 85-foot antenna station became operational, making a total of seven operational 85-foot antenna stations. Three DSN stations (Goldstone; Canberra; and Madrid) were modified by constructing additional floor space to provide joint support with colocated 85-foot antenna stations in the Manned Space Flight Network.

NASCOM. Each of NASA's tracking and data acquisition networks possesses a control center; Goddard Space Flight Center for STADAN and the Manned Space Flight Network, and JPL's SFOF for the DSN. Telemetry and tracking information, commands, and voice communications flow along the NASCOM lines from the worldwide stations to the control centers. NASCOM, which is managed by Goddard, serves all NASA networks.

The interlinking of the networks through NASCOM permits cross-support between all three NASA networks; thus, for example, selected Manned Space Flight Network stations support some unmanned Earth satellite missions and the Earth-orbiting phases of lunar and planetary missions. This cross-support reduces the total number of tracking facilities required. The unique real-time aspect of the NASCOM network makes it distinct among those of other government agencies. Subswitching centers, one in Australia and one in Europe, as well as at the Manned Spacecraft Center and at the SFOF, all work in conjunction to provide this integrated service.

In 1963, NASA became an operating component of the National Communications System (NCS) with OTDA providing the NASA interface with communications activities of all the Federal Government agencies and departments. NASA became the first customer for synchronous satellite service from the Communications Satellite Corporation in 1965. NASA's contract was responsible for the launching of the first commercial synchronous satellite, helping initiate worldwide communications service a full two years ahead of the expected schedule. In January 1967, NASCOM began providing network service via communications satellite.

SUMMARY

The following points perhaps summarize developments in NASA's space science and applications efforts during the 1963-1968 time period:

1. OSSA has built a strong space science program. Although severe cutbacks have occurred recently, the U. S. is presently in the forefront in world space science and applications.

2. Over and above the acquisition of new knowledge, space science and applications have contributed importantly to the larger purposes of the space programs; such as international good will and the technological strength of the Nation.

3. OSSA and OTDA have provided the scientific knowledge and technical knowhow essential to the success of the Apollo manned lunar landing.

4. OTDA has constructed a global spacecraft tracking and data-handling system which is an important national resource.

5. Science and applications programs undertaken by OSSA have accomplished that which they were intended to do, and all have produced useful results.[104]

NOTES TO CHAPTER IV

1. Robert L. Rosholt, An Administrative History of NASA, 1958-1963, Washington: NASA SP-4101, 1966.

2. Goddard Space Flight Center operates STADAN and the Manned Space Flight Network. JPL operates the Deep Space Network.

3. William R. Corliss, The Evolution of the Satellite Tracking and Data Acquisition Network (STADAN), Greenbelt: Goddard Historical Note 3, X-202-67-26, 1967.

4. See, for example, House Committee on Science and Astronautics, 1969 NASA Authorization, Hearings before the Subcommittee on Space Science and Applications, Part 3, Washington: GPO, 1968, p. 166.

5. Kennedy's call for a "great new American enterprise" describes the challenge well. The challenge of scientific accomplishment and its relationship to international prestige posed by the space flights of the Soviet Union is not discussed in this chapter.

6. Interview of Homer E. Newell, July 11, 1968. All interviews by author unless otherwise noted.

7. NASA Authorization for Fiscal Year 1967, Hearings before the Senate Committee on Aeronautical and Space Sciences, Washington: GPO, 1966. These very general statements are buttressed by a long list of specific objectives.

8. Scientists' Testimony on Space Goals, Washington: GPO, 1963, p. 3.

9. Astronautics and Aeronautics, 1966, Washington: NASA SP-4007, 1967, p. 47.

10. Science and Applications Management, Program Review Document, Washington: NASA, 1967, pp. 4-5.

11. For complete rosters as of early 1964, see: House Committee on Science and Astronautics, 1965 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1964, pp. 1346-1349.

12. For Mission Board rosters, see: NASA Authorization for Fiscal Year 1969, Hearings before the Senate Committee on Aeronautical and Space Sciences, Washington: GPO, 1968, pp. 355-356.

13. Interview of Homer E. Newell, July 11, 1968.

14. For a detailed history of the NASA-SSB relationship, see: Charles M. Atkins, NASA and the Space Science Board of the National Academy of Sciences, Headquarters Historical Note 62, Washington: NASA, 1966.

15. The OSSA planning cycle is discussed in depth in: Science and Applications Management, Program Review Document, Washington: NASA, 1967, pp. 22-34

16. Space Research: Directions for the Future, Washington: Space Science Board, 1965.

17. A Review of Space Research, Washington: NASA Publication 1079, 1962.

18. Interview of Oran Nicks, July 5, 1968.

19. Hugh L. Dryden, The Role of the University in the Exploration of Space, paper given before the Autumn Meeting of the National Academy of Sciences, Seattle: 1965.

20. See Representative Karth's opinion: House Committee on Science and Astronautics, 1965 NASA Authorization. Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1964, p. 1895.

21. See Chapter VI for a financial summary and further details on the Sustaining University Program. Additional description can be found in two Program Review Documents entitled University Programs, Washington: NASA, 1965 and 1966.

22. Richard Landers, Man's Place in the Dybosphere, Englewood Cliffs: 1966.

23. In addition to the documentation cited in the following review, there exists an immense accumulation of historical data in the following sources: OSSA Project Development Plans, Status Reports, and Headquarters -- Field Center correspondence. Time considerations made it impossible to tap this reservoir of information.

24. For Explorer launch schedule, see House Committee on Science and Astronautics, 1969 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1968, p. 235. Also, see Appendix.

25. It is impossible to describe the great variety of Explorer spacecraft here. See Corliss, ibid.

26. The results of NASA space physics research are described in detail in the following series of documents: Significant Achievements in Space Astronomy, Washington: NASA SP-91, 1966; Significant Achievements in Ionospheres and Radio Physics, 1958-1964, Washington: NASA SP-95, 1966; Significant Achievements in Particles and Fields, 1958-1964, Washington: NASA SP-97, 1966; Significant Achievements in Planetary Atmospheres, 1958-1964, Washington: NASA SP-98, 1966; Achievements in Solar Physics, 1958-1964, Washington: NASA SP-100, 1966; Significant Achievements in Space Science, 1965, Washington: NASA SP-136, 1967; Significant Achievements in Space Science, 1966, Washington: NASA SP-155, 1967.

27. The first group of five Pioneers was launched between 1958 and 1960, the most successful of which was Pioneer V which provided data from 18 million miles.

28. Astronautics and Aeronautics, 1964, Washington: NASA SP-4005, p. 135, 1965.

29. NASA Release 65-380. For a description of AOSO program and accomplishments, see House Committee on Science and Astronautics, 1966 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1965, pp. 570-578.

30. House Committee on Science and Astronautics, 1967 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1966, pp. 26-27.

31. There were advanced versions of OGO (the AOGO) and OAO (the AOAO) that never reached the development phase.

32. A summary of OAO schedule delays can be found in House Committee on Science and Astronautics, 1967 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1966, p. 66.

33. Headquarters OAO Review Board Report. A summary can be found in House Committee on Science and Astronautics, 1969 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1968, pp. 313-316.

34. RAE Press Kit, Washington: NASA, 1968.

35. House Committee on Science and Astronautics, Project Ranger, Report of the Subcommittee on NASA Oversight, Washington: GPO, 1964. Also see: Investigation of Project Ranger, Hearings before the Subcommittee on NASA Oversight, Washington: GPO, 1964.

36. Astronautics and Aeronautics, 1963, Washington: NASA SP-4004, 1964, p. 477.

37. Project Ranger, op. cit., pp. 12-15.

38. The scientific results from the Ranger, Lunar Orbiter, and Surveyor flights can be found in: Significant Advances in Planetology, 1958-1964, Washington: NASA SP-99, 1966; Significant Advances in Space Science, 1965, Washington: NASA SP-136, 1967; and Significant Achievements in Space Science, 1966, Washington: NASA SP-155, 1967.

39. Bruce K. Byers, Preliminary History of Lunar Orbiter Program, Washington: NASA HHN-71, 1967, which is being revised.

40. Ibid., p. 35.

41. House Committee on Science and Astronautics, 1965 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1966, p. 1413.

42. See Appendix for launch dates.

43. For a discussion of Lunar Orbiter results and their interpretations, see: N. J. Trask and L. C. Rowan, "Lunar Orbiter Photographs: Some Fundamental Observations," Science, vol. CLVIII, December 22, 1967, p. 1529.

44. William R. Corliss, Space Probes and Planetary Exploration, Princeton: 1965, Chapter 3.

45. For details, see House Committee on Science and Astronautics, Project Surveyor, Report of the Subcommittee on NASA Oversight, Washington: GPO, 1965.

46. Ibid., p. 4.

47. Ibid., p. 24, for a summary of the recommendations.

48. For details on the Surveyor flights, see a series of NASA reports entitled Surveyor I, Surveyor III, etc., in the NASA SP series.

49. The Surveyor program originally included more than seven spacecraft. In particular, there was a heavy version (2500 pounds vs. 2150) planned for later flights. These spacecraft were eliminated from the program on December 13, 1966.

50. Oran Nicks' rationale is an excellent example. See House Committee on Science and Astronautics, 1969 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1968, p. 692.

51. Corliss, loc. cit.

52. House Committee on Science and Astronautics, 1965 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1964, pp. 1806-1812.

53. For spacecraft descriptions and discussions of results, see the Significant Achievements series cited in fn. 26 and O. W. Nicks, A Review of Mariner IV Results, Washington: NASA SP-130, 1967.

54. See testimony of Edgar M. Cortright, House Committee on Science and Astronautics, 1967 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1966, p. 92.

55. J. D. Anderson, et al, "Mariner V Flight Past Venus," Science, vol. CLVIII, December 29, 1967, p. 1665.

56. For details on the Mariner 1969 program use see, House Committee on Science and Astronautics, 1969 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1968, pp. 97-112.

57. Biology and the Exploration of Mars, Washington: NAS/NRC, 1965.

58. See earlier section on NASA relations with the Executive Branch for a discussion of the attempts to sell Voyager.

59. A description of the Voyager program as of 1967 can be found in House Committee on Science and Astronautics, 1968 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1967, pp. 436-447.

60. Interview of Homer E. Newell, July 11, 1968.

61. See Newell's rationale for employing man in space, House Committee on Science and Astronautics, 1968 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1967, pp. 954-959.

62. Ibid., p. 954, for a list of significant scientific results from manned space flight.

63. Some historical details for this program can be found in: Manned Space Science, Program Review Document, Washington: NASA, 1964, pp. 10-14.

64. For a succinct summary, see: House Committee on Science and Astronautics, 1968 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1967, pp. 960-968.

65. A recent summary of the Apollo Lunar Survace Science program (including ALSEP and the ATM) can be found in: House Committee on Science and Astronautics, 1969 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1968, pp. 131-158 and 299-310.

66. Marshall Space Flight Center has project management responsibility for the ATM.

67. Life Sciences, Program Review Document, Washington: NASA, 1966, p. 1.

68. The programs are too diverse and complex to report here, see: House Committee on Science and Astronautics, 1969 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1968, pp. 349-375.

69. The Air Force biosatellite was initially called BOSS (Biological Orbiting Satellite System).

70. Astronautics and Aeronautics, 1963, Washington: NASA SP-4004, 1964, p. 320. For an early description of Bios, see: House Committee on Science and Astronautics, 1965 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1964, pp. 1941-1951.

71. For the failure evaluation and recovery plan, see: House Committee on Science and Astronautics, 1968 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1967, pp. 834-838.

72. Preliminary results are reported in: House Committee on Science and Astronautics, 1969 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1968, p. 338.

73. For example, see A. C. Clarke's 1945 paper "Extraterrestrial Radio Relays," Wireless World, October 1945, and his note in the April 1945 issue.

74. Space Applications Summer Study -- 1967 Interim Study, National Academy of Sciences, Washington: GPO, 1968, vol. 1, p. 3.

75. The early interplay among programs is discussed in: Edgar W. Morse, Preliminary History of the Origins of Project Syncom, Washington: NASA HHN-44, 1964.

76. Ibid., p. 29.

77. The early history of the NASA and DOD communication satellites and the establishment of Comsat Corp. is extremely involved. Since it falls outside the time frame of this history, the reader should consult: Eugene M. Emme, A Chronology on Communications Satellites, Washington: NASA HHR-11, 1963; National Communications Satellite Programs, Hearings before the Committee on Aeronautical and Space Sciences, Washington: GPO, 1966.

78. An Advanced Syncom project was sponsored at Hughes by NASA; it contributed advanced hardware to Early Bird.

79. A fuller statement of NASA responsibilities can be found in: House Committee on Science and Astronautics, 1969 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1966, pp. 374-375.

80. For a summary of ATS results, see: House Committee on Science and Astronautics, 1969 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1968, pp. 446-449.

81. The original code name was Janus. For details, see: John H. Ashby, A Preliminary History of the Evolution of the Tiros Weather Satellite Program, Washington: NASA HHN-45, 1964.

82. See Appendix for the launch dates of the Tiros series.

83. Richard Chapman, Tiros-Nimbus: Administrative, Political, and Technological Problems of Developing U.S. Weather Satellites, Washington: NASA Historical Draft, 1966.

84. Ibid., for details.

85. Ibid., Chapter VIII.

86. Goddard also studied a synchronous meteorological satellite called Aeros, which has some resemblance to ATS.

87. See Newell's testimony on R&D aims for Nimbus: 1966 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1965, pp. 889-893.

88. A review of results from Nimbus I and II can be found in: House Committee on Science and Astronautics, 1968 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1967, pp. 697-702. Also, consult: Significant Achievements in Space Applications, 1965, Washington: NASA SP-137, 1966; Significant Achievements in Space Applications, 1966, Washington: NASA SP-156, 1967.

89. House Committee on Science and Astronautics, 1969 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1968, p. 492.

90. Interview of Leonard Jaffe, July 9, 1968.

91. Communications and Navigation, Program Review Document, Washington: NASA, 1964, p. 13.

92. For a detailed discussion of ATS results, see: House Committee on Science and Astronautics, 1969 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1968, pp. 444-458.

93. For details, see: House Committee on Science and Astronautics, 1968 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1967, pp. 723-736.

94. For a list of current objectives, see: House Committee on Science and Astronautics, 1969 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1968, p. 430.

95. Secretary of Interior Stewart L. Udall announced this program on September 20, 1966.

96. House Committee on Science and Astronautics, 1969 NASA Authorization, Hearings before the Subcommittee on Space Sciences and Applications, Washington: GPO, 1968, pp. 430-449.

97. Space Applications Programs, Program Review Document, Washington: NASA, 1967, pp. 49-52.

98. Ibid., pp. 56-61, for a more thorough discussion of the international aspects.

99. Centaur Launch Vehicle Development Program, Report of the Committee on Science and Astronautics, Washington: GPO, 1962, pp. 5-9.

100. Goddard Space Flight Center operates STADAN, while JPL operates the DSN.

101. See Chapter VII. Also: Gerald M. Truszynski, International Benefits of Cooperative Tracking and Data Acquisition Agreements, Washington: NASA, 1968.

102. William R. Corliss, The Evolution of the Satellite Tracking and Data Acquisition Network (STADAN), Greenbelt: GHN-3, 1967.

103. Ibid., p. 67.

104. For an excellent photographic summary of a decade of space effort, see Edgar M. Cortright, Exploring Space With a Camera, NASA SP-168, 1968.

CHAPTER V

Chapter V

RESEARCH AND TECHNOLOGY: AERONAUTICS AND SPACE*

(1963 - 1968)

The late Hugh L. Dryden, the last Director of the National Advisory Committee for Aeronautics (NACA), NASA's predecessor, and NASA's first Deputy Administrator, once noted that mission-oriented agencies like NASA serve to establish the research base that is fundamental to the long-term national interest.[1]

All NASA flight missions are preceded by and, during their operational phases, are backed by major programs of advanced research and technology. These are carried out in laboratories of NASA and other government agencies, in universities and industry. The overall NASA research and technology program ranges from basic research to applied research and advanced technological development, and there are literally thousands of research efforts under way at any one time. These range through the physical and biological sciences, engineering science, space propulsion technology, vehicle systems technology, space operations technology, tracking and data acquisition and processing, and even some socioeconomic studies.[2]

Such research, while vital to the development of new aeronautical and space-flight systems, is considerably less well-known to the general public than is the activity associated with the building and flying of these systems and conducting experiments with them. Research and technology activities only rarely are newsworthy. It is this lesser known but fundamental area of the NASA's activities which will be described in this chapter.

ORGANIZATION AND MISSION

The roots of flight research and technology in the Federal Government stem from 1915 when the National Advisory Committee for Aeronautics (NACA) was created. The purpose of

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*This chapter was prepared by Irwin Hersey.

NASA's distinguished predecessor agency was to "supervise and direct the scientific study of the problems of flight, with a view to their practical solution, and to determine the problems which should be experimentally attacked, and to discuss their solution and their application to practical questions."[3] During its 43-year lifetime, NACA won world-wide acclaim for its basic contributions to aeronautics. It may truly be said that every American airplane that flies, military and civil, bears the imprint of NACA research.

In 1958, when the National Aeronautics and Space Administration came into being, it inherited the NACA organization with its $300 million research facilities in four major laboratories -- the Langley Research Center, Langley Field, Va.; the Ames Research Center, Moffett Field, Calif.; the Lewis Research Center, Cleveland, Ohio; and the Flight Research Center, Edwards Air Force Base, Calif. -- and its highly-experienced and competent staff of 8,000.[4] The new challenge of space made clear, however, that considerably more was needed than research, and NASA's charter was consequently much broader than that of the NACA, calling on the Agency to "plan, direct and conduct aeronautical and space activities."[5]

To carry out this mission by developing, and later flying, launch vehicles, satellites and spacecraft, an Office of Space Flight Development, headed by Abe Silverstein, was formed in NASA Headquarters to manage all space programs, in parallel with an Office of Aeronautical and Space Research, headed by Ira A. Abbott.[6] The latter continued the NACA research role in aeronautics while considerably expanding research related to space systems.

The Office of Aeronautical and Space Research had become the present Office of Advanced Research and Technology (OART) late in 1961. The Office was headed first by Thomas Dixon, and Dixon was succeeded by Raymond L. Bisplinghoff in 1962, by Mac C. Adams in 1965, and by James M. Beggs in 1968.*

NASA's research and technology effort during the 1963-68 period continued to center in the Office of Advanced Research and Technology (OART). The role OART played in the NASA research and technology effort, however, was by no means

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*See biographies in Volume II, Appendix A-IV-1 and NASA organizational charts in Appendix A-I.

an exclusive one, since during this period the three other major program offices in NASA headquarters -- the Office of Space Science and Applications (OSSA), the Office of Manned Space Flight (OMSF), and the Office of Tracking and Data Acquisition (OTDA) -- all had extensive supporting research and technology (SRT) programs of their own.* SRT proposals by these offices were reviewed by OART and coordinated so as to assure a balanced and effective over-all research effort.

Under the heading of advanced research and technology, supporting research and technology (SRT) in OART included fundamental work in the aerospace sciences, and more applied technology programs intended to meet particular technological objectives (performance, weight, etc.) in a given time-frame, in anticipation of the needs of future NASA missions. In the Office of Manned Space Flight (OMSF), on the other hand, SRT included both advanced development programs designed to develop long-lead-time items for manned projects soon to be initiated, and supporting development programs aimed at providing back-up or alternate systems for projects already under way. The SRT program of the Office of Space Science and Applications (OSSA) was designed to provide support for its six major program areas and to develop space science experiments, while its advanced technical development program, like that of OMSF, developed long-lead-time hardware for future unmanned missions. Finally, in the Office of Tracking and Data Acquisition (OTDA), the supporting research program was directed toward providing new and improved tracking and data acquisition systems.[7]

By its very nature, OART research was less program-oriented than that of the other major program offices, which were much more concerned with the day-to-day progress of specific missions, and particularly with the development of hardware for mission-oriented programs. Raymond L. Bilpling-hoff, OART head from 1962 to 1965, once defined the objective of the Office as being "to advance the technology of flight in the atmosphere and space through research" in four areas. The first was directed at gaining a better understanding of the general phenomena underlying aeronautical and space vehicle technology. The second involved reducing this basic understanding of the physical world to design methods or precedures for such vehicles. The third centered on the systematic testing of

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*It should be noted here that "SRT" is actually an envelope encompassing a wide variety of research, technology, and development programs.

vehicle concepts to obtain design data, and the fourth, with the pioneering development of advanced subsystems for those vehicles.[8]

Similarly, Mac C. Adams, who succeeded Bisplinghoff as the head of OART, described the office's role in these terms:

> We are charged with developing meaningful technologies for future aeronautical and space vehicles. We also assist in solving problems arising in existing vehicles or those in development. A third objective is to increase knowledge in the scientific and engineering disciplines basic to aeronautical and space vehicles and their operation.[9]

Even though the OART work tends to be less program-oriented than that of the other program offices, it must be planned in conjunction with the plans of the agency as a whole. Thus, the planning of research and technology programs must provide for the attainment of technological objectives which contribute to the conduct of attractive future missions which, themselves, serve to fulfill agency goals. In 1965, OART established a new Mission Analysis Division (MAD) as part of OART headquarters, but situated at the Ames Research Center. This division has primary responsibility within OART for analyzing attractive future missions in aeronautics and space flight as they contribute to the achievement of national goals. These analyses clarify the technology objectives that must be reached pursuant to establishing the technical base for going ahead with these missions. OART found, as had been hoped, that the results of these mission analyses were of great value in identifying not only the most important technologies to work on, but also the proper pacing of the efforts so that the full technology base for attractive future missions could be provided in their proper relative time frame. Accordingly, the important concepts of a balanced over-all program providing new technology on a timely basis for attractive future missions has taken on new quantitative significance and effectiveness in OART, and has been utilized in planning the program since FY 1967.

In the planning process, the mission options considered derive from the studies of key organizations both within and without NASA, and are consolidated and critiqued by the MAD. Both the former groups and the MAD identify the key technological advances important to these missions, and the OART Program Divisions respond with corresponding program proposals. This process is an iterative process, of course, and the final program proposal for each fiscal year represents the best thinking of the OART headquarters management, the OART Center Directors, and the potential users of the technology (e.g., the other NASA program offices and other government agencies).

The more fundamental research is, of course, not planned in the same manner. Its planning is delegated to the field center directors to a large degree. In this way, the characteristic of basic research to flourish in an environment free of unnecessary constraints is best enhanced. Indeed, it is usually the basic research which leads to the unexpected "breakthroughs" and to the identification of new mission possibilities not previously considered.

In Fiscal Year 1968, the OART program budget was more than $300 million, or about 8 percent of the total NASA R&D appropriation.[10] During the 1963-68 period, actual funding was as follows: Fiscal Year 1964, $317.1 million; FY 1965, $332.3 million; FY 1966, $288.6 million; FY 1967, $268.8 million; FY 1968, $312.8 million.* If supporting research and technology funds from the other program offices are added to these figures, the annual total reached some $400 million annually.[11]

For the most part, the NASA advanced research and technology effort enjoyed favorable Congressional support during the five years from 1963 through 1968. Members of the House Committee on Science and Aeronautics and the Senate Committee on Aeronautical and Space Sciences have been quite sympathetic to the goals of the NASA advanced research and technology effort, and little inclined to differ with the agency on the need to carry out research.

By 1967, however, there were fiscal shortages and resulting constraints on the overall NASA budget. By the time appropriations hearings were held on the Fiscal Year 1969 budget, in the spring of 1968, it seemed clear that the major reductions required in agency appropriations would inevitably result in the reduction of funding for some major research and technology programs. One such program was the development of a nuclear rocket engine. In the summer of 1968, NASA, under strong budgetary pressure, announced an "interim operating plan for Fiscal Year 1969" in which development of the NERVA nuclear rocket engine would be put off until at least the next fiscal year.[12]

Many NASA officials expressed concern over this development, as well as other cuts in the Agency's advanced research program, and pointed out that it is imperative to <u>increase</u> research expenditures when operations funding is reduced, so that the new technology required for future projects will be available when the budget pendulum swings back up again. Similar concerns were expressed by Congressional supporters of NASA.[13]

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*Note that the increased funding in FY 1968 reflected a major increase in aeronautical research and technology, and was otherwise little changed from the years immediately preceding.

The inherent difficulty in ascertaining the "why" and "how" of major decisions in research and technology was pointed out by Mac C. Adams at a Senate hearing.[14] He was asked to explain his statement that OART did not make decisions on new national projects, but merely furnished the technical information on the projects necessary to insure that such decisions and their implementation had a sound technical base. He replied that it was the prime responsibility of OART to "provide the basic technical information required to support decisions to proceed with new national technological developments, to consult and advise on the reaching of these decisions, and to bring attention to alternative and possible new developments." He added that OART has served this function in the case of major space programs, military programs and the supersonic transport.

As an example, Adams noted that the decision to proceed with the Quiet Engine Program was made by a Committee formed by the office of Donald F. Hornig, science adviser to President Johnson, after OART had provided the technical background on the possibilities for solving the noise problem and proposed alternative solutions.[15] In the specific case of the Quiet Engine Program, the decision was influenced by Congressional concern about the aircraft noise problem. And, of course, in the case of the supersonic transport, the actual decision to go ahead with development of the vehicle was made, after more than two decades of NACA/NASA, DOD and FAA research, by the President himself.[16]

While it is difficult to subdivide the NASA research and technology effort in an entirely satisfactory manner, programs tend to fall into one of three broad categories: basic research applicable to a broad spectrum of aerospace programs; aeronautical research and technology directed more specifically at aeronautical applications; and space research and technology oriented to space programs. These three categories are examined in detail in the sections which follow.

BASIC RESEARCH

Basic research in NASA is carried out in large degree by the OART Research Division. In general, this research centers on programs in materials sciences and engineering, in electro-physics, fluid dynamics and applied mathematics. As noted earlier, this work provides the engineering knowledge upon which advances in vehicle and systems technology are based.

Materials Sciences and Engineering

One important effort at NASA during the last few years has centered on the evolution of forged ceramics. The motivation for the development of high-density, deformed ceramics was the need for better jet and rocket engines, which in essence meant engines capable of operating at higher temperatures. NASA, along with other Government agencies and private industry, was a major contributor in this effort. It has not only produced a whole class of new materials, but also developed techniques for processing materials at temperatures as high as 4500 degrees F., compared with processing temperatures less than half as high during World War II.[17]

Another major research area which appears promising, although the promise is yet to be completely fulfilled, is that of metal whiskers. Whiskers have been studied for years because of their potential for strengthening other materials to which they are added, but have not come into widespread use because of their high cost. In one NASA program, whiskers of a very high strength oxide (sapphire) have been used to stitch together the grains of an alloy. It was found that the use of as little as one percent of whiskers would strengthen the material enormously. The technique is very promising, but is confined at this point to the manufacture of welding rods because it is still quite expensive.[18]

The various ablative materials developed by NASA also appear to have great potential, although unrealized as yet. In addition to their use in various aerospace applications, such materials could conceivably be of great value in the construction of safer automobiles, and perhaps even in building structures, where I-beams could be coated with an ablative material to keep buildings from collapsing in the event of fire.[19]

The new ladder polymers are also regarded as very important, particularly a new class of stable polymers called Pyrrones, developed at Langley in 1965. Pyrrones have unique properties, such as high resistance to heat and radiation, stability at temperatures as high as 900 degrees F., and tensile strength which is not degrated by electron radiation of very great intensity. The only problem is that materials of this type are not very oxidation-resistant. Nevertheless, Pyrrones seem promising for many industrial uses.[20]

One other area of NASA material research during this period is worthy of mention. Studies of why dry metals wear and seize when rubbed together led to the important discovery that the frictional characteristics of metal surfaces depend on the pattern and spacing of the metal atoms. Thus, a hexagonal arrangement of the atoms allows much freer sliding than a cubic arrangement. It was also learned that changes in atomic spacing caused by impurity atoms was also important. Since these arrangements can be changed by alloying or by thermal or mechanical means, it may be possible to control dry friction.[21] The action of artificial hip joints has already been improved by applying the principles and techniques discussed here in their manufacture.

Fluid Physics

Fluid physics research has produced a number of important discoveries about radiant heating encountered during atmosphere entry during the last few years.[22] In 1966, for example, progress was made for the first time in determining the radiative properties of air at temperatures above 15,000 degrees F., needed to design the configuration and heat-protection systems of possible future entry vehicles.[23]

In 1967, the fluid physics program emphasized studies of the radiant heat generated by the high-temperature gas cap in front of the re-entry vehicles at entry velocities in the range of 40,000 - 70,000 fps. The new Langley Hot-Gas Radiation Facility completed in 1968 was expected to be a major contributor to these continuing studies.

In 1968, the Ames Research Center studied ways and means of taking advantage of the fact that spacecraft heat shields ablate at reentry speeds greater than 50,000 fps and form a sort of blanket over the surface which protects the vehicle from heat transfer by convection by preventing the very hot gas behind the front shock wave from coming into contact with the surface. As a result, the potential heat transfer by radiation will be the dominant factor in designing protective heat shields for entry vehicles exposed to velocities of this order. Because radiative heat transfer is strongly dependent on the bluntness of the vehicle, increasing linearly with nose bluntness, the answer may be to go to more slender configurations with a slightly blunted tip. This possible solution was under active investigation in 1968.[24]

Electrophysics

In 1964, it was discovered that the irradiation of materials by exceptionally intense pulsed laser beams generated coherent hypersonic sound waves of greater intensity and higher frequency than had been obtained previously. These waves provided a new tool for probing the structure of matter and nondestructive testing of materials.[25]

Two years later, a laboratory investigation was started to find out whether electrostatic forces are important in the formation of tornadoes, the premise being that the tornado cloud derives its high angular momentum from an electrostatic motor type of action.[26]

Another program of great interest has centered on the problem of increasing supercritical temperatures. In 1967, it was found that the electron pairs responsible for superconductivity could be formed not only of electrons in the body of the metal, as is usually the case, but also of electrons initially separated from each other by a thin insulating barrier. Using a sandwich of thin-film layers of aluminum separated by a silicon monoxide insulator, the superconducting temperature increased to more than double its value in bulk aluminum.[27] Other programs led to the detection of the existence of hydrogen-4 by a University of Virginia group working at the Langley Space Radiation Effects Laboratory.[28]

In addition, the Jet Propulsion Laboratory has developed the first space-charge-limited, solid-state, germanium triod. Another JPL program was directed toward vastly increasing memory storage capacity through the use of a ferromagnetic thin film such as manganese bismuth as a storage device. A laser beam was used to store the data and read it out. The importance of this development can be judged by the fact that storage densities up to 10 billion bits per square inch of storage area are possible with such a technique, compared to the 10 cubic feet required to store the same amount of data in today's computers.

The Electronic Research Center has produced the highest frequency ever obtained in a Gunn oscillator, 30 kilomegahertz, and used it to send voice transmissions from the Center to the Prudential Tower in Boston. ERC has also produced a tunnel-diode pressure transducer of such small dimensions that it has been placed on the end of a catheter and fed into a dog's artery. It transmits an oscilliscope signal, using minimal power.[29]

Applied Mathematics

Emphasis in this field has been on obtaining new, more accurate and faster solutions to problems of a space mechanics nature, and on improved mechanical techniques for investigating the flow fields around a body or within a body inlet moving at hypersonic speeds. In recent years, new computational techniques for solving complex equations have been developed, providing solutions of greater accuracy and requiring less computer time. Improvements have also been made in calculating the ephemerides of planets.[30]

AERONAUTICAL RESEARCH AND TECHNOLOGY

The hearings held in January and February 1967, and the subsequent report in January 1968, of the Senate Committee on Aeronautical and Space Sciences on Aeronautical Research and Development Policy, must be numbered among the most significant events in this area during the past five years. Following the hearings and the Committee Report there was a rise in expenditures in aeronautical research. And, in 1968, in accordance with a recommendation of the Committee, there was created the new post of OART Deputy Associate Administrator (Aeronautics), with the appointment of Charles W. Harper to the post.

The Senate hearings[31] and Report[32] were preceded by an equally important Staff Report on the subject prepared for the Committee by the Legislative Reference Service of the Library of Congress.[33] Particularly significant in the Committee Report was the statement that, "although NASA was established on the foundation of excellence of aeronautical research of the National Advisory Committee for Aeronautics (NACA), this important activity has receded into the background within NASA."[34]

Actually, the record shows that aeronautical research has played a key role in OART throughout NASA's history. All the successive Directors of the OART Aeronautical Vehicles Division -- John Stack, Charles H. Zimmerman, Charles W. Harper and A. J. Evans -- have argued persuasively for increased emphasis on aeronautics, and their requests were favorably endorsed by all of the Associate Administrators for Advanced Research and Technology.

In testimony before the Senate in May 1965, for example, Raymond L. Bisplinghoff pointed out that, while support for aeronautics had risen substantially in the past few years, pressure for a still greater effort was mounting because of the phenomenal growth in commercial air transportation. Also, additional pressure had developed because of the trend within the Department of Defense away from broadly-based research and toward specific developments for definable operational requirements.[35] Bisplinghoff and his Deputy, Alfred J. Eggers, Jr., have been credited with major roles in bringing about the very substantial increase in funding of aeronautical research during the past two years.[36] Research funds for aeronautics rose from $35.9 million in Fiscal Year 1967 to $66.3 million in FY 1968 and $76.9 million in FY 1969.[37]

The Senate study of <u>Policy Planning for Aeronautical Research and Development</u> was already under way, and NASA was already giving increased attention to aeronautics when an OART management meeting was held in Washington on January 19-20, 1966. At the meeting, the directors of the Langley, Lewis, Ames and Flight Research Centers and OART head Adams came to the conclusion that now was the time to focus attention on aeronautics and place additional emphasis on it.

A key proponent of this point of view was Abe Silverstein, Director of the Lewis Research Center, who had already begun to shift research emphasis at Lewis back to aeronautics. The result has been that many former aeronautical propulsion specialists who had turned from aeronautical to space research after NASA was formed had been returned to their old field of aeronautics with new perspectives, renewed insight and interest.[38]

Aeronautical research and technology at NASA during the 1963-68 period has focused on avionics; human factors; aircraft operating problems of various kinds; general-aviation aircraft; subsonic, supersonic and hypersonic aircraft; vertical and short take-off and landing aircraft; and the experimental X-15 and XB-70 aircraft.

Avionics

Electronic aids to navigation, guidance, turbulence detection, collision avoidance, all-weather operations and automatic landing all help integrate man and machine into a more efficient unit. However, it has been found that a strong need exists for further integration of such systems into an optimum total system, and NASA has been trying to fill this gap by applying its space electronic research experience to avionics.

Among the projects of major interest in this area have been the development of technology which can lead to an advanced avionics system for future supersonic aircraft; the design and development of general-aviation avionics, as discussed above; and development of an effective collision-warning indicator.[39]

One promising collision-warning possibility which has been developed involves the use of xenon flashing lights and electronic detectors. The xenon lights not only provide a brilliant flash, but also emit a large amount of infrared energy, which can penetrate clouds and be picked up by an infrared detector and used to alert the pilot. Tests conducted in 1967 indicated the technique was feasible.[40]

Human Factors

NASA has been carrying on an intensive investigation of human response to noise while seeking to obtain a better understanding of how it affects people both physically and psychologically. Toward this end, measurements and human-reaction surveys have been made in a number of cities; studies have been made of community response to the noise produced by different kinds of aircraft; and a considerable amount of research has been carried out on the effect of the sonic boom on human subjects.[41]

Another major area of human-factors research has centered on development of an on-board aircraft oxygen system which could supply the needs of crew and passengers from water without the need for carrying a supply of oxygen, thereby greatly reducing the need for ground support. TRW, Inc., has been developing for the Ames Research Center a system, based on space life-support systems and technology, which would obtain its oxygen from water electrolysis and be independent of the atmosphere.[42]

It has long been recognized that aircrew performance deteriorates with fatigue, and NASA has been doing a considerable amount of research in this area. In one program, an elastic vest-like garment which contains large, segmented, dry silver-coated electrodes was developed by the Flight Research Center to measure the physiological effects of flight stresses.

Using several such electrodes permits a physician to visualize the heart's electrical activity in three dimensions.

Ames Research Center has studied ways and means of reducing crew workload in one of the most demanding flight situations -- a Category II landing, in which there is a minimum ceiling of 100 feet and a runway visual slant range of 1,250 feet. The Center has adapted a piloted flight similator to study the workload problem, with the degree of physiological stress experienced by pilots in such situations determined by measurements of blood and urine.[43]

Aircraft Operating Problems

Three important programs, typical of many in operations, were: the aircraft noise-reduction, the prevention of skidding on airport runways, and fog dispersal. These programs were highlighted at a "NASA Technical Conference on Aircraft Operating Problems" at the Langley Research Center May 10-12, 1965,[44] and effort continues on them.

In the area of aircraft noise, NASA has concentrated on three approaches: one, a short-range solution, was directed towards suppressing the noise generated by current engines by means of acoustical absorption techniques, in the hope that the noise could be reduced to an acceptable level until such time as a more quiet engine could be designed and built. Another program investigated the possibility of changing aircraft characteristics and equipment so that steeper approach and take-off flight paths can be used. The third, and much longer-range, solution was centered on development of the much talked-about "quiet" engine, where low noise is part of the design requirement. While noise alleviation studies at the agency go back a number of years, it intensified in 1966, due, in part at least, to public protests and a subsequent Congressional concern about the growing problem because of the increase in jet transportation.

In 1966, while continuing basic research on the fundamentals of aircraft engine noise generation, NASA became part of an interagency Government aircraft noise-abatement program. At the same time, the NASA expanded its research to include studies of the noise-generation characteristics and potential for noise reduction of full-scale engine components.

As a follow-up to this approach, contracts were let during 1967 to both McDonnell-Douglas and Boeing for modification of the engine nacelles of existing fanjet aircraft such as the Boeing 707-320C, the objective being to achieve a sizable reduction in fan-compressor noise during the landing approach. Significant noise reduction has been achieved in the program and data from it are already being disseminated throughout the entire aircraft industry, although the research is still underway.[45] In 1967 NASA also carried out flight tests of five multi-engine jet transport aircraft in an effort to see if steeper approach and take-off profiles could be used for noise reduction. The conclusion was that such a technique could reduce noise to a considerable degree, but that considerably more study would be required before operations of this kind could be employed. These studies continued through 1968, with particular emphasis on the development of new direct-lift control devices which would enable pilots to fly the steep flight paths required.[46]

A long-range noise-reduction research effort, and one with enormous implications for the future, has centered on the development of a so-called "quiet" engine. This effort also got under way in 1967 at Lewis Research Center with new engine cycle studies and an analysis of the possibilities of fitting an engine of this kind on current and planned jet transport aircraft. The engine under study was in the 20,000 - 25,000-pound-thrust class, with a high bypass ratio range (between 3 and 8), which would reduce exhaust noise to an acceptable level. The ultimate goal was an engine which would be considerably quieter than comparable engines in the 20,000-pound-thrust class.[47]

Several possible fan, compressor and turbine combinations were studied, and by 1968, research had reached the point where selection of the best possibilities for detailed design, fabrication and later testing could be made. One area under intensive investigation was fan design, since the fan becomes the main source of engine noise as exhaust noise is reduced through the use of a high bypass ratio.[48]

In another operations problem, NASA has for a number of years carried out ground environment studies designed to eliminate or minimize the dangers of skidding on wet or icy runways. The areas investigated have included tire-to-runway traction, anti-skid braking systems, hydroplaning, air jets for water and slush removal, runway grooving, runway surface textures, pneumatic tire dynamics and tire-tread design parameters. These studies have direct applications to automobile highway safety problems and have contributed to research carried out by the Department of Transportation on highway traction problems. In 1967, a limited number of tests indicated that transverse grooving on runway surfaces could prevent loss of traction. Aircraft landing and taxiing tests continued in 1968 on the landing loads track at the Langley Research Center while awaiting completion of a specially-prepared grooved runway at Wallops Island. Planned for testing were NASA's 990 and Lear Jet aircraft, as well as an F-4C jet fighter at the request of the Navy, and a C-141 jet at the request of the Air Force.[49] Meanwhile the FAA and the airport operators in selected locations throughout the country were cooperating with NASA in a series of tests of grooved runways and taxiways with a variety of configurations and utilizing grooves of varying sizes to provide information on the effect of routine traffic, the use of snow-removal equipment, and other factors on the grooves and the aircraft, and to test the effectiveness of grooving on dry, damp, flooded and slushy conditions.

Another NASA research program has been concerned with methods of dissipating warm fog. Laboratory experiments in 1967 indicated that visibility could be significantly increased by seeding the fog with small amounts of salt crystals of carefully controlled size.[50] In the fall of 1968, a series of tests of the salt-seeding concept under actual warm fog conditions at the Elmira, N.Y., airport indicated that salt-seeding constituted an effective method of dissipating such fog.

General-Aviation Aircraft

This is another area which has attracted increasing attention in recent years as a result of major growth in private, executive, and air-taxi aviation.

In 1967, NASA purchased a light twin-engine aircraft representative of the general-aviation class to obtain baseline aerodynamic data necessary to define problem areas requiring further study. In 1968, wind-tunnel studies were made of the aircraft at the Langley Center 30 X 60-foot wind tunnel in order to assess state-of-the-art levels of performance, and the stability and control characteristics of such aircraft.[51] Research in 1968 also included a study of the effects of engine nacelles on lift distribution.[52]

NASA has also had a general-aviation avionics (aviation electronics) program, directed toward providing the technology for development of new avionic gear which could reduce the pilot's workload in the cockpit; improving aircraft handling qualities; designing and developing better stability-augmentation systems; and furnishing more effective pilot displays.

In the area of control systems, new flight-control techniques have been studied. In conventional aircraft, the response to a control input by the pilot, such as a command to turn, is an acceleration in roll up to a limiting roll rate. By using flight-control techniques, the same input can result in a constant rate of roll response, or with more complexity, an attitude response corresponding to pilot input. Research showed that the latter control mode was easier to fly, and it is this area which was under active investigation during 1968.[53]

While the general-aviation aircraft supporting technology program was still quite small, amounting to only $0.5 million in Fiscal Year 1969,[54] it promises to grow into an important area of NASA research in the years that lie ahead.

Vertical and Short Take-Off and Landing Aircraft

There is a long and continuing history of vertical and short take-off and landing (V/STOL) research and technology at NASA, a good deal of it carried out in cooperation with other Government departments. Thus, NASA has worked with the Army in the development of the rigid-rotor concept, and with the Army and the Air Force on the fan-in-wing, tilt-wing and tilt-rotor concepts.[55]

During the past five years, research in this area has been accelerated by the need to develop advanced V/STOL concepts for military service and by the increasing need for domestic center city-to-center city transportation. Under these pressures, NASA has carried out research on the most promising concepts and vehicle types.

In 1964, for example, the Agency's V/STOL program included flight tests of the NC-130B boundary-layer control aircraft; simulator studies and wind-tunnel and flight tests of a deflected slipstream STOL aircraft; flight tests of a tilt-wing test bed, a vectored-thrust jet and a variable-stability helicopter, as part of a program to establish criteria for V/STOL flying and handling qualities; and wind-tunnel studies of models of the Tri-service tilt-wing transport, the Navy tilt-duct aircraft, and the Army fan-in-wing vehicle.[56]

The following year, a major program in this area got under way when NASA contracted with three aircraft manufacturers for feasibility studies of the research required to develop promising V/STOL concepts into useful aircraft for commercial short-haul transportation systems. These were continuing in 1968, the problem being that no single V/STOL aircraft type simultaneously met the requirements of ample hover time, critical for maneuvering around the airport, and high cruise speed, necessary for good economy.[57]

Simultaneously, wind-tunnel studies were continuing on the aerodynamics of various V/STOL concepts, particularly those of interest to the military, such as the tilt-wing (XC-142A) type, the tilt-duct (X-22A) type and the lift-cruise fan type. Investigations were also conducted of inlet and exit interference effects, including those resulting in hot-gas reingestion.[58]

A "NASA Technical Conference on V/STOL and STOL Aircraft," held at the Ames Research Center, April 4-5, 1966, provided a useful focus on research problems and prospects. The 500 engineers and scientists from government and industry who attended the meeting heard reports on the progress of NASA research on the aerodynamic, propulsion and handling qualities of such aircraft, as well as the Boeing, Ling-Temco-Vought and Lockheed feasibility studies of concepts for short-haul transportation.[59] Research to 1966 had indicated that the rotating-cylinder-flap and augmentor-wing concepts appeared to offer more efficient STOL capability, and that the hingeless-rotor and jet-flap rotor appeared to have special potential for extending or improving the flight capability of the helicopter.[60]

The fall of 1967 saw the beginning of construction of the new Langley V/STOL transition tunnel, continued wind-tunnel studies of lift-fan and other VTOL models potentially applicable to military requirements, and inauguration of a program at the Lewis Center to improve V/STOL propulsion concepts, particularly the lift fan.[61]

The 1968 programs included efforts to improve helicopter cruise performance without sacrificing landing capability; initiation of flight tests of the XV-5B fan-in-wing aircraft; studies of pilot workload in the jet-lift P-1127; and an investigation into the possibility of adapting the Gemini guidance computer, inertial reference system and power supply to a V/STOL guidance and control system.

This last project, if successful, could have significant implications for the entire aerospace program, since it would represent one of the first successful transfers of hardware originally developed for space use to aeronautics.[62] The first limited series of tests conducted at Langley in September 1968 was successful.

Subsonic Aircraft

The interest of the Senate Committee on Aeronautical and Space Sciences in aeronautical research and development during the 1966-68 period unquestionably had a major effect on aeronautical research in general and in particular on research on subsonic aircraft.

In the area of aerodynamics, for example, there was a resurgency of interest in transonic flow, with Lewis Research Center investigating the problem of inlet-engine-nozzle dynamics and interaction, particularly in the transonic regime.[63]

One of the most important research programs in subsonic aerodynamics gave rise to a completely new concept, a super-critical airfoil wing which would delay transonic drag rise and thus increase the range and speed of subsonic aircraft. Development of the supercritical wing can be traced back to the discovery in 1965 that slotting the upper rear surface of a properly-shaped airfoil could move the shock wave to a point near the back of the wing, resulting in an 18 percent increase in speed before high drag was encountered.[64]

While this improvement was notable, NASA researchers were not satisfied because slotting the wing increased weight, structural complexity and fabrication costs. The research was therefore continued in order to gain a better appreciation of the dynamics involved, and it was found that much the same thing could be accomplished without using the slot. The new supercritical wing permitted thicker wing sections to be used without increasing weight, and this meant a higher lift/drag ratio, with a resultant increase in range and payload. Research on this very promising concept continued in 1968, with particular emphasis on its application to military aircraft.[65]

It should also be noted that all of the work in the area of noise suppression during the 1963-68 period, discussed earlier, has been in the field of subsonic jet aircraft.

Supersonic Aircraft Program

Early NACA research going back to 1945 and 1946 was a major contributing factor in the design and development of the present commercial supersonic transport (SST) aircraft. NACA's early contributions were immediately utilized in military aircraft, particularly the XB-70 and fighter types. In the past five years, NASA supersonic aircraft research was generally concerned with problems which came up in the course of the SST development effort and with problems associated with possible advanced supersonic aircraft.[66]

In the fall of 1963, a review of SST research at a "NASA Technical Conference on the Supersonic Transport," held at the Langley Center, indicated that a safe, reliable SST was technically feasible, but that additional research would be required to obtain the necessary economy of operations. It was also noted at the Conference that a dominant design factor would be the requirement that sonic-boom intensity not exceed certain arbitrary values, that titanium alloys appeared very promising from both the weight and temperature standpoint; and that new and advanced engines would be required.[67] In the intervening years, NASA has concentrated its attention on these three major problem areas, and has also studied new problems as they arose in the inter-agency development effort.

In 1964, NASA SST research concentrated on methods of uprating the capabilities of the various design concepts. During the following year, intensive investigations were carried out on the sonic-boom problem and the radiation environment the SST would encounter in high-altitude flight. In addition, the experimental XB-70 aircraft, which was similar to the SST in many respects, was used for the first time in sonic boom experiments. In 1966, it was indicated that relatively minor changes in the shape of a large airplane like the SST could appreciably alleviate sonic-boom overpressures, and that design changes of this type could be used to produce a smaller, shorter-range aircraft which would minimize sonic-boom generation over domestic airways.[68] This approach was followed up in subsequent studies.

The year 1967 was marked by the birth of a new and very important research tool, the general-purpose airborne simulator (GPAS). The GPAS is a modified Lockheed Jetstar commercial transport in which NASA installed a complex variable stability and control system so that its flying characteristics could be changed at will. It was initially used to duplicate the supersonic flight characteristics of the XB-70, as part of a program to validate the simulation capabilities of that aircraft. Experiments showed that, at an altitude of 20,000 feet and at Mach 0.55, the GPAS accurately matched the motions of an XB-70 operating at 55,000 feet and at Mach 2.35.[69]

The flying simulator was employed during 1968 to determine SST handling qualities and piloting problems which might require additional research. By this time it was already giving promise of becoming an extremely versatile research tool, capable of providing detailed investigations of the handling qualities of a variety of high-speed aircraft in their early design stages.[70]

By 1968, NASA's supersonic aircraft program had three major parts. The first was directed toward support of the FAA, SST program management, and its contractors. As the development program proceeded, technical problems often arose, and NASA facilities and research capabilities frequently represented the best available national resource for solving many of these problems. The second activity was directed toward the solving of potential SST problems. This generally involved studies of the flight dynamics of the proposed SST design, with the objective of aiding FAA in its definition of what its design characteristics should be. This research required the efforts of large numbers of NASA technical personnel and the use of complex in-flight and ground-based simulators, and constituted the main objective of the XB-70 flight-test program.

The third NASA activity involved research on more advanced supersonic aircraft, such as a "second-generation" SST, the principal areas of investigation being propulsion and avionics. The original SST design did not approach the maximum potential in either of these areas, and theoretical work, as well as laboratory studies, indicated that significant improvements could be made in both.

Consequently, the 1968 propulsion program centered on research on propulsion-system inlets, compressors, burners and blades. Three new blade designs were under study, each capable of providing more aerodynamic lift, or carrying a greater load, than the original SST blade design. In addition, research on combustors produced results that would permit the construction of shorter and lighter engines for the SST. Other studies centered on the development of new high-temperature materials for use in turbine blades.[71]

The XB-70 Program

The Mach 3 XB-70 aircraft made a number of major contributions to the NASA aeronautical research program during the past four years. Under Air Force program management, NASA began using the experimental Air Force bomber in its research on supersonic transports during 1964 to obtain data on aerodynamics, structures and loads, propulsion, and operations under true environmental conditions.[72] Full participation by NASA in the program was delayed by the tragic deaths of NASA test pilot Joseph A. Walker and Air Force Major Carl S. Cross on June 7, 1966, when Walker's F-104 chase plane apparently hit two vertical stabilizers of the $500-million XB-70-2 at an altitude of 25,000 feet. XB-70 pilot Al White ejected in his seat capsule and parachuted to earth, suffering minor injuries, but Major Cross went down with the aircraft. Walker, at the time of his death, held world records for his 4,104 mph and 354,200-foot altitude flights in the X-15.[73] The accident put off the first flight in the joint NASA-Air Force program until November 1966.

Priority research areas for the program included the sonic boom; dynamic loads; stability, control and handling qualities; engine-inlet performance; and general aircraft performance.[74] By January 1967, the XB-70-1 had completed the last of nine sonic-boom flights, while two additional flights the same month supplied additional data on handling qualities and evaluated a new fuel. At the end of the month, it was decided to transfer program management, operational control and funding responsibility from the Air Force to NASA, and the transfer took place in March. The aircraft continued to obtain research data in the same areas as previously for the balance of the year.[75]

Before the program was phased out at the end of 1968, the XB-70 had been used in studies of the response of large flexible supersonic aircraft to wind gusts. Equipment which sensed the response of the aircraft to strong gusts of wind and deflected the control surfaces to reduce the response was installed. With the conclusion of this high-priority work, the program was completed.[76] One major factor in the decision to end the program was the availability of the GPAS to replace the XB-70 in SST simulation. The GPAS was found to be capable of matching XB-70 responses, and thus SST responses, almost exactly, and was much less expensive to operate.[77]

The XB-70 made a number of major contributions to the SST development program. It provided basic aerodynamic data on this class of aircraft, making direct measurements of skin friction at the highest Reynolds numbers ever recorded; it verified sonic boom signatures for large aircraft; it provided flight operations experience with an SST-class aircraft and indicated that handling an aircraft of this size and speed did not pose any major problems.[78]

Hypersonic Aircraft

The NASA supporting technology program in hypersonic aircraft is designed to "develop theoretical approaches and analytical design techniques, and to provide experimental data against which the adequacy of the theories can be judged."[79] In general, this program has centered on research on the behavior of structures and materials exposed to extremely high heating rates; the aerodynamics of hypersonic flow, and studies of possible propulsion systems for such a vehicle. In 1964, for example, studies showed that a vehicle powered by an air-breathing engine had advantages over a ballistic vehicle for near-earth rendezvous missions, although aerodynamic heating would be a critical problem in the development of such a vehicle.[80]

Hypersonic aircraft concepts also posed multiple problems to the structural designer. In 1964, a program was initiated to use heat-resistant materials for the construction of two sizable structural fuselage test specimens embodying new concepts, and two years later, two structural concepts for hypersonic vehicles were identified and investigated. The first of these was a multiwall sandwich concept which combined the evacuated thermal-protection, tankage and load-carrying functions into a single component. The second was based on an unsealed structure using carbon-dioxide gas to purge the insulation space between structure and tanks.[81]

The following year, three parallel contracts let under the Hypersonic Research Engine program -- a joint effort of the Langley, Ames and Lewis Centers to design, develop, build and flight-test to Mach 8 an advanced supersonic combustion ramjet engine -- indicated the feasibility of the concept and produced data directly applicable to the design and construction of such an engine.[82]

The X-15 Program

During the entire 1963-1968 period, the X-15 program provided invaluable information on hypersonic flight, obtained under full-scale flight conditions. This information was of vital importance in validating the results of studies of hypersonic flow theory and design-prediction techniques utilizing small-scale ground-test facilities.[83] The remarkable X-15 flight-test record[84] was marred by the accidental death of Air Force Major Michael J. Adams on November 15, 1967, after a flight to an altitude of more than 260,000 feet. Major Adams' aircraft, X-15-3, crashed in the Mojave Desert after the final portions of the reentry maneuver. The flight was Major Adams' seventh in the X-15 aircraft and the 65th for the X-15-3. This was the first and only fatality in the 191 flights made to that date since the X-15 flight-test program got under way in June 1959.[85]

Among the many and varied accomplishments of the X-15 were the following:

1. In contrast to earlier expectations of extensive laminar boundary layers in hypersonic flight, the X-15 experienced largely turbulent flows.

2. Turbulent heating rates on the X-15 were found to be significantly lower than predicted by the available theories; also, direct measurements of skin friction were significantly lower than predicted. These findings stimulated extensive wind-tunnel investigations of the problem and a reexamination of the theories in this area.

3. The flight program confirmed man's ability to pilot an areospace vehicle in varying situations ranging from a high-speed, rocket-boosted exit phase, through space-flight reentry maneuvers, to high-speed, lower lift-over-drag glide landings.

4. The program established the importance of a simple stability-augmentation system in providing acceptable handling characteristics at high Mach number.

5. It demonstrated the successful utilization of a self-adaptive control system.

6. It proved the value of the "pilot plus redendancy" concept. In 13 of the first 44 flights, the aircraft would have been lost had these factors not been present.

7. The X-15 served as a most valuable test bed for a large variety of experiments -- in ultraviolet steller photography; micrometeorite collection; tests of Apollo-related horizon scanners and photometers, and infrared earth and sky scanners; studies of atmospheric density at high altitudes; studies of ablative coating, etc.[86-88]

The 100th flight of the X-15 program was made in January 1964 and in June of the same year, the X-15-2, modified for Mach 8 flight for the study of stellar ultraviolet radiation and for testing advanced airbreathing engines, made its maiden flight in modified form. A decision was also made at this time that the X-15 should be utilized through 1968 for obtaining research data in the areas of aerodynamics, airbreathing propulsion and structures.[89]

In 1966, two flights of the X-15-2 were made with the large external propellant tanks required for Mach 8 flight. The second flight, on November 17, was entirely successful, producing data on handling characteristics with full external tanks, tests of ablative materials, and several test-bed experiments. The flight also produced the greatest speed recorded to that point in the program, 4,233 mph, or Mach 6.33.[90]

On October 31, 1967, an X-15-2 flight was carried out with external tanks and a dummy hypersonic research engine installed, and with the entire aircraft coated with a special ablator. While a record speed of 4,534 mph was achieved by Air Force Major William J. Knight in the flight, shock waves generated by the hypersonic engine shape interacted with the boundary layer on the ventral fin, resulting in damage to the fin.[91]

The X-15 program ended in 1968 after completion of all the various experiments planned for it.[92]

SPACE RESEARCH AND TECHNOLOGY

While NASA expenditures for aeronautical research and technology have been rising for the past two Fiscal Years, the funding of space research has absorbed and continues to absorb a much larger proportion of total NASA research expenditures.[93]

Heavy funding has been demanded by a broad research effort which has ranged, often in hitherto unexplored research frontiers, all the way from studies of the reentry problems to research on nuclear rockets; from the development of new guidance and control systems to studies of new kinds of parachutes; and from the development of exotic space power systems to research on new bio-instrumentation. The areas in which major research and technology programs are found are space vehicles, electronics and instrumentation, chemical propulsion, nuclear rockets, space power and electrical propulsion, and human research and biotechnology.

Space Vehicles

During the 1963-68 period, NASA has had continuing programs in the areas of lifting-body spacecraft, parachutes and recovery systems, and structures and materials.

The results obtained in the lifting-body program have been of importance to future spacecraft design, since as orbital traffic increases, some means must be sought for reducing operating costs. One obvious step would be to develop spacecraft capable of entering the atmosphere and landing at selected fields, thus greatly reducing recovery costs. Another significant step would be the development of techniques which would make possible the reuse of space vehicles. The lifting-body program has made important contributions in both these directions.[94]

The NASA lifting-body spacecraft program has four basic objectives: To investigate approach and landing problems; to evaluate the handling qualities of this type of vehicle; to determine control-system requirements; and to correlate wind-tunnel and flight characteristics.[95] During 1964, the flight program of the original lightweight Ames M-2 lifting-body configuration was completed after well over 100 flights. The results clearly indicated that a man could enter the atmosphere and safely fly and land a lightweight lifting-body aircraft. Based on the promise of the lightweight vehicle, two similar vehicles with realistic spacecraft weights were ordered.

The M-2 configuration is basically half of a 13-degree cone which has been sliced along the longitudinal axis, with a canopy added for increased pilot visibility and twin tails used for stability and control. The Langley-developed HL-10 is essentially a highly swept, very thick, inverted delta wing with a large center fin and two smaller outboard tails for stability and control. Each vehicle is about 22 feet long. Minimum weight is 5300 pounds and maximum gross weight is about 10,000 pounds. In flight testing, the vehicles are carried aloft by a B-52 to an altitude of about 45,000 feet, released at a Mach number of about 0.8, and then, under pilot control, glide to a landing at the Flight Research Center, gathering research data during the entire return flight.

The M-2/F-2 was delivered in mid 1965, the HL-10 a few months later and, after wind-tunnel tests, the flight testing phase of the program got under way in 1966.[96] The M-2/F-2 made 15 successful flights before it was damaged in a landing accident in May 1967. The HL-10, which exhibited some deficiencies in its initial flight the previous December, underwent additional wind-tunned testing during 1967 before being modified for the resumption of flight testing. The modified HL-10 made its second flight in March of this year. In addition, the Air Force delivered a third lifting body, its own X-24A, to the Flight Research Center in 1967, and tests of this vehicle were scheduled as part of a joint NASA-Air Force program late in 1968.[97]

Considerable progress has also been made during the past five years in the development of parachutes and recovery systems, since the more conventional spacecraft, not capable of horizontal landing, would also benefit from the ability to land at a predetermined recovery site. In 1964, the Langley Center completed a series of successful flight tests of a hot-air balloon which could be stowed in a container aboard a spacecraft and deployed at an appropriate altitude much like a parachute. This type of system would permit the pilot of a spacecraft to select an appropriate landing site or allow a soft landing without the use of impace attenuation devices.[98] Meanwhile, research continued at the Manned Spacecraft Center on reliable techniques for recovering manned spacecraft, and a single large parachute capable of recovering a 10,000 pound spacecraft was developed.[99]

Research has also been carried out on advanced lifting parachutes capable of landing the Apollo spacecraft on land and steering it to pre-selected landing sites.[100] One concept understudy since 1965 is the "limp paraglider," a lightweight triangular device somewhat like a parachute which can be packed and deployed like a conventional parachute. A drop-test program was initiated in 1967 which was designed to expose large parachute systems to flight conditions representative of a full-size returning manned spacecraft.[101]

There has also been an ongoing program in planetary entry devices. One parachute designed for use in entering very thin atmospheres is of the "disk-gap-band" type, which makes extensive use of open areas or large-scale porosity in the parachute canopy for more stable decent. Tests in 1967 indicated good performance at altitudes as high as 140,000 feet. The following year, flight tests began on parachute systems for the Voyager program, which was designed to land a spacecraft on the surface of Mars. Experiments were carried out successfully with 85-foot parachutes. In 1967, a flight program to determine the deployment, performance and stability characteristics of parachutes suitable for decelerating a probe in the Martian atmosphere was completed.[102]

Research on planetary landing parachutes was still going on in 1968. Two parachute configurations have been identified as having satisfactory characteristics for use in Mars probe applications, and detailed design data have been obtained which show that such parachutes can be made to operate properly at considerably higher speeds than was previously believed possible.[103]

In the area of structures and materials, research in 1964 had indicated that large, lightweight structures could be completely packaged for launching and then expanded in space for use as rentry of solar-power systems, or as radio telescopes. In addition, it was found that the use of expandable structures as lunar shelters could increase the safety and reliability of manned lunar missions.[104]

The following year a program to investigate structures which might be used as shelters on the surface of the moon was instituted, using the Apollo lunar module without basic modification to transport two men and a shelter to the moon. Research on filament winding, thermal-control coatings, meteoroid penetration and expandable structures developed the technology required to design and construct a sample shelter module.[105]

Also in 1965, new fabrication processes involving joining by diffusion were developed in research on sandwish materials, and a comprehensive assessment of the diffusion bonding of metallic structures was completed.[106] In addition, studies of techniques for attenuating the landing impact of spacecraft led to an efficient concept involving cyclical material deformation. Its advantages included simplicity of operation, the ability to be adjusted to various conditions, reusability and light weight.[107]

In 1966, analytical studies determined the feasibility of constructing and deploying in space a very large, lightweight radio-telescope antenna with a 1-mile diameter. The antenna would be an open grid of fine wire or ribbon which would be relatively insensitive to meteoroid hits.[108]

In 1967, a new type of construction was developed at the Lewis Research Center for pressure vessels which consisted of a metal tank wrapped with glass filaments, with optimum compression induced in the metal by appropriate tension in the glass fibers. Experimental models showed increased reliability and weight saving over temperatures ranging from -423 to +75 degrees F.[109]

Ever since the Space Age began, engineers and scientists have been struggling with the problem of how to protect space vehicles against the potentially harmful environmental effects of space -- vacuum, abnormally high and low temperatures, the absence of gravity, meteoroids, radiation, etc. The past five years have seen some important progress in determining the meteoroid environment and providing protection for vehicle structures against meteoroid impacts; learning how to control fluids under zero-gravity conditions; and adding to the body of knowledge on thermal/vacuum effects and spacecraft temperature control.

In the area of meteoroid studies, three Pegasus launched in 1965 made it possible to measure meteorite penetrations in large-area, relatively thick skin samples.[110] Data from these spacecraft, coupled with information obtained by Explorer XXIII, resulted in changes in Apollo meteoroid design criteria. In another program, data from the Lewis Research Center's zero-gravity program formed the basis for design of the propellant-management systems used in the Centaur and S-IVB stages.[111]

In the area of space radiation and shielding, NASA has been concerned primarily with the acquisition of theoretical and experimental data on the transmission of high-energy particles through elementary shielding materials and the generation of secondary radiation within these particles. Most of this information is now in hand, and recent research has centered on the experimental determination of the shielding effectiveness of various kinds of space-vehicle structures.[112]

Thermal-radiation studies have sought ways and means of providing better control of spacecraft temperatures. One of the best ways to do this is to put coatings on the exterior of space vehicles which either accept or reject thermal radiation. One major problem is that such coatings tend to degrade in the space environment, and recent research has centered on finding out why this is so and what can be done to keep it from happening.[113]

Electronics and Instrumentation

Research in electronics and instrumentation tends to fall into four categories: Control, guidance and navigation; communications, tracking and data acquisition; electronic techniques and instrumentation; and data processing.

Steady progress has been made in the development of advanced control, guidance and navigation systems. In 1964, the basic feasibility of the cryogenic gyroscope was successfully demonstrated in laboratory tests. Also, a simple, lightweight but reliable passive attitude control system developed at Ames was selected for use in the Applications Technology Spacecraft program.[114] The following year, progress in the development of the electrostatic gyro led to initiation of a NASA-Air Force effort to incorporate the gyro into a strap-down inertial navigation system. Meanwhile, advanced concepts were being applied to the design of a star tracker for the Orbiting Astronomical Laboratory, and an all-axis, inertially-coupled, gravity-gradient stabilization system was being developed for the Advanced Technology Satellite.[115]

In 1966, development was begun of a three-axis ring laser gyro for evaluation in a strapdown inertial platform. Such a system would eliminate the complicated gimbaling systems now employed as reference platforms in aircraft as well as spacecraft. More recently, a concept using a single-axis ring laser was tried.[116]

In addition, a program was initiated in 1966 to measure the radiance characteristics of the earth's horizon as a basis for the development of highly accurate navigation and attitude control sensors.[117]

One of the most important developments in this area is the control moment gyro (CMG), to be used on the Apollo Telescope Mount. The steps leading to its development are typical of how research ideas evolve in NASA.[118]

The control moment gyro is essentially a momentum storage device, and its development dates all the way back to late 1960, when the Langley Research Center began control studies for large orbital stations. A spinning space-station concept was examined first because it was inherently stable and provided artificial gravity. Analysis showed that a damper would be needed to control wobbling of the spin motion. By 1963, a wobble damper concept employing a small control moment gyro was tested on an air-bearing table.

Earlier studies had been made at Langley on the control of nonspinning spacecraft, and, with the experience gained on wobble damping, it was a natural step to look at the CMG in a three-axis control system. By 1964, the CMG looked feasible in simulation tests, and in 1966 Langley procured a laboratory model CMG which was successfully static tested. Shortly thereafter, the CMG was selected by the Marshall Space Flight Center as the method to be used in stabilizing the Apollo Telescope Mount. Research to date indicates that the CMG, with additional work, could prove useful for a large optical telescope, a manned laboratory, or a similar application.[119]

Major advances have also been made in communications, tracking and data acquisition. In 1964, the Goddard Space Flight Center initiated a series of experiments using lasers for satellite tracking. In the first tests, Explorer XXII was successfully tracked from Goddard, while England, France and several industrial organizations also conducted laser tracking experiments using the satellite. The same year a program was initiated to study and define the limitations, implementation and problems and research areas associated with the technology of narrow optical beams like lasers. Research in this area is a necessary preliminary to the application of laser to deep-space communications.

One of the most important developments in this area during the 1963-68 period came to fruition in 1965, when the Jet Propulsion Laboratory (JPL) perfected a video film converter and associated digital computer techniques for recovering high-quality picuture information from the noisy and distorted television signals received from spacecraft. A prototype of the system was used in the Ranger lunar vehicles, and an improved version played a major role in reconstructing TV photographs from the *Mariner IV* Mars spacecraft.

The film converter provides precise conversion of either analog or digital signals to film, or vice versa. It corrects geometric distortion and position displacement of picture elements introduced in the reconstruction process, and removes extraneous signals which cause streaking or false patterns in the picture. The computer techniques improve resolution and quality by removing noise and correcting distortion.[120]

This so-called "image-enhancement" technique has a number of uses outside the space field, and has already been employed to clarify medical X-rays, thus permitting better diagnoses. The process adds nothing to the picture that was not photographed originally. It merely brings out details which would otherwise be lost.

Although considerable quantities of data have been transmitted to and from spacecraft and satellites, there is every indication that a major increase in these requirements will accompany the development of many of the most useful future spacecraft, like the Applications Technology Satellites. Thus, the development of a process called Previous Element Coding in 1965 is of considerable significance. In this technique, designed to reduce the amount of redundant data transmitted from a spacecraft, electronic circuits operate on television pictures coded digitally so as to transmit only those picture elements which differ from those previously transmitted. A computer processes the received information and reconstructs the original picture by generating the missing picture elements and inserting them in their proper location in the picture.[121]

The following year, in another development in the same area, spacecraft on-board telemetry techniques were developed which remove redundant bits of information, thus reducing the total volume of data transmitted to earth, conserving power and reducing ground processing.[122]

NASA has also played a major role during the past five years in the development of a broad range of solid-state, micro-miniaturized instrumentation, including sensors of various kinds, telemetry systems and bioinstrumentation. One development in this area uses solid-state, photosensitive mosaics which can replace vidicon tubes, but have no electron beam and do not require a vacuum. Other developments in the instrumentation field included a vibrating diaphragm pressure transducer capable of measuring seven decades of pressure, and the use of lasers to measure atmospheric density, a technique which may prove useful in the detection of clear-air turbulence.[123]

In solid-state work, the first phase of an investigation of thin-film, laminated ferrite material for possible use in the construction of high-speed, large-capacity, low-power, small volume and weight, computer memories was completed in 1964.[124] Also, under the direction of the Electronics Research Center, research was carried out on a thin-film, radiation-resistant, space-charge-limited semiconductor triode with a higher tolerance to radiation than conventional devices.[125]

In 1966, Ames Research Center developed biotransmitters with integrated circuits, miniature components and high accuracy. One of the uses of this instrument is in a unique circuit which permits constant calibration of the temperature sensing element, and has an operating life, with a single miniature battery, of 5,000 hours. Similar transmitters, using thin-film resistive gages as heat sensors, and a capacitance transducer to measure pressure, weighing less than an ounce, were used in wind-tunnel facilities to measure heat-transfer data and after-body pressure on spacecraft models.[126] Another development has been segmented optics, which would permit high-resolution space telescopes to be assembled and aligned in space. After initial assembly, a mirror figure sensor would determine which segments were out of alignment and provide electrical signals to actuators located behind the mirror. A 24-inch, three-segment mirror feasibility model was ground-tested in 1966 to evaluate the technique, with encouraging results.[127]

NASA, along with industry and other government research laboratories, has also been studying large-scale integrated circuits. Electronic component life and reliability have increased by orders of magnitude as transistors replaced vacuum tubes and in turn were replaced by integrated circuits. These have a number of components, such as transistors, resistors, etc., formed and connected on a single chip of silicon to perform a complete electronic function.

The success of single-function integrated circuits has led to large-scale integration which, with the use of the new field-effect transistors, permits the construction of larger circuit arrays performing a variety of functions. Devices performing as many as 100 functions have been flown on IMP satellites and performed well. They appear to have enormous promise for the future.[128]

Research in the area of data processing has been directed toward increasing the flexibility, reliability, efficiency and utility of computer systems. Toward this end, NASA programs have led to advances in techniques to improve random-access memories; demonstrations of the feasibility of micropower logic devices; research on the development of onboard computer elements immune to space radiation, construction of "plated-wire" memory units; and work on fluidic logic and amplifying systems.

One particularly interesting development has been in the area of holography. At the Electronics Research Center, holography has been used for data storage, and has permitted a remarkable degree of data compression in the storing of star patterns.[129]

Chemical Propulsion

The NASA research and technology effort in chemical propulsion over the past five years has laid the foundation for a whole new family of space systems -- systems capable of effecting considerable reductions in the cost of putting a pound of payload in orbit.

The developments singled out as being of particular significance during this period include the successes achieved in the large solid-rocket motor program; the development of hydrogen-oxygen systems; the much-improved picture in the area of space-storable propellants; and the development of high-performance restartable solids.[130]

One of the most impressive achievements during the period under construction here was the large solid-rocket program. By the time the program was terminated in 1967, the series of three successful firings of the 260-inch-diameter motor, plus the ten firings of the 156-inch-diameter solid engine by DOD, had clearly suggested that a booster of this class could be successfully developed if and when a decision was made to do so.[131] The motor in the third test firing, on June 17, 1967, which reached a peak thrust of 5.8 million pounds, was the most powerful rocket motor ever built.

During the past five years, NASA has also had a continuing research program on high-performance solid propellants. The program has included investigations of the kinetics of composition, ignition, combustion and combustion stability, physical properties, motor case and nozzle materials, and propellant manufacture, processing and loading. At the same time, applied research has been carried out on restart and thrust variation.[132]

In 1966, significant results were achieved in identifying and understanding solid-propellant combustion phenomena, including the effects of metal particles in propellants containing oxygen. The relationship of various types of acoustic losses to other losses was also clarified. Both these efforts marked important steps toward the understanding and control of combustion instability in large solid motors.[133]

Studies last year of small, high-energy solid rockets for space propulsion applications indicated that the addition of beryllium to the Surveyor decelerator motor fuel would have increased the useful payload by 45 percent, and two firings of such a motor confirmed the predicted performance level.[134]

Advanced solid-propellant motors which provide a higher specific impulse and also can be stopped and started on command have been under investigation for space propulsion. Combustion in this type of engine would be stopped on command by water injection and restarted by multiple igniters. Combined solid-liquid, or hybrid engines have also been studied because of their start-stop and variable thrust capability.[135]

In the area of liquid propulsion systems, the 1963-68 period witnessed the final stages of development of the 1.5 million-pound-thrust M-1 liquid hydrogen -- liquid oxygen engine, including the successful testing of major engine components, before the program was phased out in 1966 because there was no near-term requirement for development of a vehicle using such an engine.[136]

SUPPORTING RESEARCH AND TECHNOLOGY PROGRAMS

OF OTHER NASA PROGRAM OFFICES

The Office of Advanced Research and Technology was not alone among the NASA Program Offices in conducting supporting research and technology (SRT) programs. All the other Program Offices and their respective field centers and contractors have SRT programs. Whereas the OART program is aimed primarily at developing technology for attractive future missions and at providing a sound base of aerospace technology, the SRT programs of the other offices are closely oriented to support of their ongoing and near-term future missions. In the case of the Office of Space Science and Applications, however, fundamental research and technology in space sciences and associated scientific instruments is also included. The total SRT program of this office is a very sizeable one*, currently running at the rate of some $75 million per year.[156]

Each of the major OSSA program areas -- Lunar and Planetary Programs, Physics and Astronomy, Launch Vehicles and Propulsion Programs, Space Application Programs, and Bioscience Programs -- has its own SRT program, specifically tailored to its particular needs.

Thus, SRT in the Lunar and Planetary Programs area, for example, includes theoretical work, laboratory research, observational studies and instrument development in each of four different areas -- cartography, planetary astronomy, planetary atmospheres and planetology. The cartography SRT program is designed to provide geodetic, topographic and cartographic information on the Moon and planets; the planetary astronomy program to obtain data about the Moon and planets from observations made in the vicinity of earth; planetary atmospheres, to obtain information about the gaseous envelopes of the Moon and planets; and planetology, to gain greater insight into the origin and evolution of solar-system bodies through increased knowledge of their composition, surface features and the forces acting on them.

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*See Chapter IV.

Building on the data obtained in the M-1 program, the Agency's advanced launch-vehicle engine program has centered on two concepts for an advanced cryogenic engine -- the toroidal plug, or aerospike, engine and the high-chamber-pressure engine.[137] The high-pressure engine is of conventional shape but compact; the aerospike engine has a toroidal, or doughnut-shaped, combustion chamber and nozzle, making the engine short and very compact. Both have potential for large boosters and advanced spacecraft capable of atmospheric entry and landing. In the area of space propulsion, this period also witnessed the successful testing of the 15,000-pound-thrust RL-10 engine with a fluorine-hydrogen combination in 1964.

There has also been an intensive effort aimed at developing space-storable propellants, an effort which has achieved some excellent results. Two space-storable propellant combinations have been selected as being the most promising. Oxygen difluoride with diborane offers the maximum performance potential, but a mixture of fluorine and oxygen, commonly called FLOX, in the proper proportion, can be substituted for the oxygen difluoride. While somewhat more cryogenic, the FLOX mixture has the advantage of easy availability and lower cost.[138]

Nuclear Rockets

It has been almost universally acknowledged that the nuclear rocket program has been one of the most successful NASA research and technology efforts. A joint project with AEC, the effort has centered on nuclear rocket graphite-core (the NERVA program) technology and on advanced nuclear rocket technology, with emphasis on tungsten-core and gaseous-core systems.[139]

The NERVA portion of the program has been directed toward the ultimate development of a flight-type engine using a graphite-core reactor. A major milestone in the technology program was reached in December 1967 when the NRX-A6 reactor was run for an hour at full power, twice the time previously achieved. Since 1964, total reactor running time at the beginning of this year was 429 minutes, of which 193 minutes was at full or near-full design power. However, full-power operation for one hour is only the first of the program goals. Design advances in the Phoebus-IB reactor indicate it may be possible to achieve the goal of 800 seconds of specific impulse at the reactor temperature demonstrated in the last A6 test, and fuel development work has been promising enough to project a specific impulse as high as 825 seconds or even more.[140]

Progress has also been made in reducing fuel-element corrosion. Improvements in the Phoebus IB reactor fuel elements resulted in a 2:1 reduction in corrosion compared with previous runs. Additional improvements in the fuel elements of the A6 resulted in an additional 2:1 reduction over the Phoebus IB result, indicating that to all intents and purposes the corrosion problem has been solved.[141] This has been singled out as one of the high points of the program during the last five years. During this period, about 90 percent of the work required to develop a nuclear engine to the point where it is ready for flight testing was completed.[142]

Another major bench mark in the program was the breadboard engine tests completed in March 1966, which showed that the engine could be built, would run, could be stopped and restarted, and could operate over a wide range of conditions.

The NERVA-Ground Experimental Engine test series, just getting under way in 1968, was designed to accomplish the rest of the engine system goals. However, shortage of funds for NASA programs in Fiscal Year 1969 were expected to push the entire program back at least a year.[143]

Space Power and Electrical Propulsion

Work in this area generally falls into one of four fields: solar electric power generation, chemical electric power generation, nuclear electric power generation, and electrical propulsion systems.

The program in solar power generation has focused on solar cells, to the near exclusion of other types of solar systems. Enough work has now been done on the other types to realize that the advantages of solar-thermal systems, for example, are marginal when compared with either solar cells or nuclear-thermal systems. It has also been realized that solar cells can be useful in ranges up to 50 kw, and during the past year the first phase of a program to develop to the point of technology readiness a 20 watt/pound, folding solar-cell array has been completed. Remarkable advances in beryllium technology to achieve very light-weight structures have marked this program.

The major accomplishment in chemical power generation has been the development of a second-generation fuel cell to technology readiness for a small part of the cost of developing the fuel cells used in the Gemini and Apollo programs. The asbestos-matrix fuel cell is neither lighter nor more efficient than its predecessor, but it is a lot more tolerant of off-limit conditions and more useful.[144]

A most significant decision was made in 1967 to pursue the development of long-life batteries, and fabrication of a five-year battery now appears possible. Until recently, long lifetimes have been achieved by running the battery for only a short period of time and then recharging it. Research on a new rechargeable battery has progressed to the point where it was selected for use in the Orbital Astronomical Observatory spacecraft scheduled to be launched in 1968, and also in the Apollo Telescope Mount. Heating during recharge and weight have been significantly reduced, and cycle life has been increased appreciably. The next step is to extend the cycle life to five years.[145]

Considerable progress has been made in the area of nuclear power generation, and particularly on the radioisotope thermoelectric generator, over the past five years. In this context, the flight of SNAP-19 on the Nimbus satellite has been singled out as a significant milestone, despite the fact that the mission was aborted.[146] Also, the decision to use SNAP-27 on the Apollo Lunar Surface Experiment Package marks another step forward. In this same area, it should be added that considerable progress has also been made in dynamic systems using turbogenerators such as SNAP-8.

In the area of electrical propulsion, resistojet engines have reached a state of technology readiness, and small engines of this type have been accepted for operational use in spacecraft position-keeping. Resistojet experiments have been flown in two Applications Technology Satellites (ATS), and delivered anticipated thrust levels in ATS-III, although additional work is required on feed system components and valves. Resistojets will perform station-keeping on the ATS-D and -E flights.[147]

It has also been demonstrated that ion engines can deliver the kind of long-time performance required for small unmanned spacecraft, and that solar-cell systems needed to power such systems are feasible and that the required weights and power levels can be achieved.

Human Research and Biotechnology

In the past five years, NASA has had a number of continuing programs in biotechnology in such fields as life-support systems, space suit development, human factors and, particularly, bioinstrumentation. Steady progress has been made toward the goal of a more efficient life-support system over the past few years, beginning in 1964, when a partially regenerative system was tested for 30 days with five men in a sealed chamber. System oxygen was supplied from chemicals stored within the chamber and all forms of water were reprocessed for use by the test subjects. The same year an advanced physical-chemical regenerative system was fabricated which was designed to operate for a year, with expendables resupplied at 90-day intervals.[148] The system was installed at the Langley Center and then tested with limited manned runs. A four-man, 30 day run was successfully completed in mid-1968, and a 90-day run was scheduled late in the year.

Meanwhile, a full-scale program in regenerative technology has been pushed. Areas which have been, and are now, under study include water and oxygen recovery; solid waste management; food management; and the development of sensors for oxygen, carbon dioxide, water vapor, inert gas and trace contaminants.[149]

Development of a hard, i.e., metal, space suit with constant-volume joints has been in progress. In addition, combinations of hard and osft suits have also been under study. As part of the research program on advanced soft suits, the Manned Spacecraft Center has been working on new materials which are flameproof and provide better thermal insulation. A new fiberglass fabric of this type has been used as the outer layer of the Apollo space suit.[150]

In the human-factors area, there have been continuing programs in cardiovascular stress physiology, respiratory stress and stress-hormone research, the latter resulting in the discovery of eleven new pituitary enzymes at the Ames Center. Another long-term program has investigated various aspects of weightlessness, and particularly the effect of weightlessness on the otolith and the role of the otolith in human balance.[151]

One recent study of stress, in which 14 men marched 110 miles in a week in Arctic cold at Fairbanks, Alaska, indicated that a compound called aldosterone may play a major role in the ability of man to withstand extreme cold and, by inference, stress of any kind. The study found an increase in the amount of aldosterone in the urine of the men who withstood the cold best during the march.

Research in the area of man-system integration has been concerned with developing the technology needed for the proper integration of man with his equipment so as to satisfactorily perform the tasks assigned him in space. The Langley Center has a program to study the effect of reduced gravity on human performance. Data have been gathered from investigations of the performance of various tasks in simulated lunar gravity (1/6th G) and under zero-G conditions. A recent study used an underwater test facility to simulate weightlessness with neutral buoyancy while astronauts perform tasks of various kinds. Another compared tasks performed in space with the same tasks performed during aircraft weightlessness flights and under water.[152]

During the past five years, the bioinstrumentation field has unquestionably been one of the most fruitful areas of study undertaken by NASA, and has led to the development of many new and unusual instruments. Particularly significant was the fact that many of the instruments developed in the course of the program have important medical or biological applications outside the aeronautics and space field.

One recent instrument, as an example, measures the velocity of blood flow if placed directly over the skin of a blood vessel by means of a strap-on ultrasonic flowmeter. Earlier, surgically implantable bioinstrumentation was developed to obtain critical physiological information from experimental animals, and, also, a spray-on technique had been developed for the rapid and secure application of electrodes for sensing electrocardiogram and other biopotentials.[153]

One biomedical instrument designed at Ames had an interesting history. Originally intended for use as a micrometeoroid detector, it was found to be too sensitive for this purpose, and today is being used by the FDA to measure the heart rhythms of baby chicks four days after incubation.[154] Another instrument in wide use was the Endoradiosonde, or "radio pill," which is actually a miniature radio transmitter which can be swallowed.[155]

SUPPORTING RESEARCH AND TECHNOLOGY

FOR OTHER GOVERNMENT AGENCIES

In his statement before the Senate Aeronautical and Space Sciences Committee hearings on NASA's Fiscal 1969 budget in March 1968, OART head Mac C. Adams reviewed the various kinds of supporting research and technology NASA performed during the previous year for other Government agencies.[160] He pointed out that in 1967 NASA completed a series of flutter tests of the C-5A aircraft in the Langley Structural Dynamics Wind Tunnel; tested the F-111 in the Langley Spin Tunnel; tested various aspects of the SST in the Lewis and Ames wind tunnels; and assisted the Air Force in studies of the low-frequency dynamic response or bending characteristics of space launch vehicles. Dr. Adams estimated that, in aircraft technology alone, about 20 - 25 percent of the time of the NASA technical staff, and 40 - 45 percent of research facility time, was devoted to assisting other government agencies.

TECHNOLOGY UTILIZATION

NASA's research and technology program, as might be expected, has been a major contributor to the Agency's Technology Utilization program.* Literally hundreds of the significant advances made in the course of research programs each year have been documented and called to industry's attention through this program.

Typical examples include a method of plating complex surfaces developed at the Lewis Center; a Lewis-developed method of combining solid lubricants with metals to achieve self-lubricating composite materials; and a new class of thermoplastic materials developed at Lewis which, when used as protective coatings, showed exceptional resistance to chemical attack, and could be applied in the form of aerosol, paint or dip.[161]

One recent biomedical instrument developed at Ames which appears to offer great promise is a tiny sensor and radio transmitter which sounds an alarm if a patient experiences breathing difficulty. The device

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*Compare Chapter VII.

The SRT program in Physics and Astronomy is combined with Advanced Studies, Sounding Rockets and Data Analysis, and is designed to develop and test new scientific instruments and satellite systems; to conduct auxiliary ground-based studies to correlate with and support data from flight programs; to provide facilities and support; and to support the analysis of spacecraft data beyond prime data analysis supported by project offices and conduct related studies leading to new ideas and innovations.

The Launch Vehicles and Propulsion SRT program is designed to provide information for management decisions on the launch vehicles and stages required for future unmanned missions through studies in the areas of propulsion; guidance, control and navigation; instrumentation and electronics; structures and materials, and vehicle engineering.

In Space Application Programs, SRT is devoted to acquiring knowledge of techniques, instrumentation and equipment to permit the development of effective space systems to provide unique and direct benefits to man on earth not heretofore feasible. This includes improving pointing accuracies; increasing available power and useful life; improving data handling; and developing and improving sensors and instrumentation in six discipline areas: Communications, earth resources survey, geodosy, meteorology, navigation and applications technology.*

In the Biosciences Program, everything except the Biosatellite program itself is SRT. This includes exobiology, planetary quarantine and sterilization requirements; physical biology, environmental biology (which includes acceleration, weightlessness, metabolism and extreme environments) and behavioral biology (sensorimotor coordination and sleep).

In practice, this adds up to an SRT program of enormous scope, but all tied in very closely with specific OSSA programs. Over the past five years, OSSA and its program offices have worked on lunar and planetary roving vehicles; large unfurlable spacecraft antennas; sensors

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*See Chapter VII.

for meteorological and other applications satellites; scientific instruments such as gas chromatographs, mass spectrometers and alpha-scattering instruments and advanced bioinstrumentation, to mention only a handful of literally hundreds of OSSA SRT projects.[157]

The Office of Tracking and Data Acquisition supporting research, on the other hand, is devoted almost in its entirety to keeping the NASA networks operating at maximum efficiency. Nevertheless, ODTA too has made some important contributions of broader significance.

While the design of the Apollo tracking network could be traced through the Mercury-Gemini network to the X-15 net, which marked NASA's entry into the complex network field, it actually marked a major step forward, since it was required to support a number of vehicles out to lunar distances. A different system was required which combined on a single HF carrier, with suitable sub-carriers, tracking, telemetry, voice communications, and command signals. Only a single, but very directional, ground antenna and a single transponder was used. Much of the technology used for the network came from the JPL planetary program, where many of the same problems had been encountered. This unified frequency concept has been, and will be, used in many other programs.[158]

Perhaps even more important, the Apollo program was directly responsible for the early use of communications satellites in space communications, since NASA approached the Communications Satellite Corp. in the winter of 1965 to request that a satellite be luanched to handle Apollo communications. The satellite was Intelsat II, and it is estimated that the NASA request helped push the timetable for operational communication satellites ahead by three years.[159]

The Office of Manned Space Flight also has supporting development and advanced development programs, the former designed to develop back-up or alternate systems for projects which are already under way, and the latter to develop long-lead-time items for future manned space flight projects.

promises to eliminate the continuous watch by nurses of infants or comatose patients suffering from windpipe obstructions.[162]

In addition, several important instances of technology utilization have been referred to in passing earlier in this chapter.

FUTURE FRONTIERS

Budget cuts in recent years have triggered a close re-examination of all research programs in order to preserve a balanced program and the continuing forward progress of the U.S. space program.

It is likely that aeronautical research will be adequately funded during the next few years, despite budget cuts. As the summary of R&D funding by program[163] shows, aeronautical research has just about doubled in the past two years, and this upward trend is likely to continue, especially in view of the recommendation of the Senate Aeronautical and Space Sciences Committee in its Report on Aeronautical Research and Development Policy that "NASA should continue to expand its aeronautical efforts, particularly in the development phase."[164]

Since it was important to NASA's own planning activity to obtain the viewpoints of nationally prominent people outside the program who can view its goals, plans and progress from a different perspective, the National Academy of Engineering in 1967 established an Aeronautics and Space Engineering Board made up of eleven distinguished engineers. NASA contracted for support of the Board and made a number of suggestions for possible areas of study.[165]

The first topic selected for a comprehensive study was the role of government in civil aeronautical development. This was responsive to another recommendation of the Committee in its Report on Aeronautical Research and Development Policy.[166] The Board's report on this subject was submitted in mid-1968.[167]

In 1967, NASA also made a major change in its advisory committee structure to strengthen its role in evaluating the over-all research program. The deficiency of the committee structure in recent years had been that some technical areas, such as space power, were not covered, and there were fourteen committees of varying specialities, all making independent recommendations. It was expected that the new structure[168] will overcome these problems. A Research and Technology Council of nationally prominent people in the aerospace field was established and chaired by former OART head, Raymond L. Bisplinghoff.[169] Seven of the Council members were chairmen of major committees under the Council, and three of the committees had subcommittees for considering technical matters in depth. By having subcommittees examine technical program content in depth, with the Council integrating the whole, NASA had established an effective advisory means of identifying gaps in its program and for assistance in achieving total program balance.[170]

Bisplinghoff has pointed out that this effort has enormous implications not only for the Agency's future work, but for the nation as a whole. He noted that OART is today the only entity in the Federal Government which has a budget to carry out research and development on systems which look far into the future.

Such research provides new technology and new hardware for future systems which, in turn, requires NASA to look forward to their use 20 years in the future in order that the technological foundations exist for future mission choices. Bisplinghoff emphasized the point that, if aeronautics and space are important, this nation must be prepared to spend money on the development of this new technology so that it will be available when needed. The military sources have been reducing this kind of research during the past five years, he added, and the old NACA-military coupling, under which NACA did the research and the military did the advanced technology development, no longer exists today. While NASA does research and advanced development work in space, it is doing only research in aeronautics. This may be a serious problem, since the military has been building fewer prototype aircraft and aircraft systems than was the case in the past. Bisplinghoff very strongly believes that NASA is urgently in need of more experimental hardware activity that is, hardware developed and constructed to explore and demonstrate the feasibility of a new concept. He believes that this activity should range all the way from building experimental aircraft and aircraft systems to the construction of experimental baggage-handling systems, if necessary. He noted that the recent report of the Aeronautics and Space Engineering Board supports this view.[171]

It was once said that the reason that NASA had an advanced research and technology program was the pre-eminence in aeronautics and space would depend "not only on current aeronautical and space operations, but also on our ability to organize and extend the underlying body of science and technology."[172] NASA accomplishments in aeronautics and space during the 1963-68 period indicated that it has had this ability, and was striving to maintain such a national capability for the future.

NOTES TO CHAPTER V

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