Chapter Two

Origins of U.S. Space Policy: Eisenhower, Open Skies, and Freedom of Space

by R. Cargill Hall

During World War II, America's civilian and military leadership embraced scientific research for a multitude of advanced weapons.[1] Indeed, at war's end in 1945, General H.H. Arnold, commander of the Army Air Forces, could confidently assure Secretary of War Robert Patterson that the United States would shortly build long-range ballistic missiles to deliver atomic explosives and "space ships capable of operating outside the atmosphere."[2] Thirteen years later, both of the programs that Arnold forecast were underway. This period, the immediate prelude to the space age, spawned America's civil and military space programs—programs that were in the beginning opposite sides of the same coin. These programs were shaped and initiated at the direction of one U.S. president, Dwight D. Eisenhower. Elements of them would become instrumental in forewarning of surprise attack, monitoring compliance with international treaties, and maintaining a delicate peace between the Soviet Union and the United States. For contemporary reasons of national security, the actions that framed this enterprise and the space policy that President Eisenhower and his advisors created for it were made obscure even to many of those directly involved.

Beginnings of the American Space Program

When in late 1945 General Arnold counseled the secretary of war on prospective weapon developments, he also acted to ensure that the Army Air Forces would in the future be equipped with modern weapons superior to any held by a potential adversary. The Army Air Forces commander set up an independent consultant group, Project RAND, to perform operations research and provide advice. To guide a formative RAND and oversee aeronautical research, he created a new position at Army Air Forces headquarters, that of Deputy Chief of Air Staff for Research and Development. Arnold selected Major General Curtis E. LeMay for this position, a young man with a reputation for accomplishing formidable assignments.[3]

During 1946 and 1947, at a time of demobilization and declining budgets, LeMay directed improvements in research and development. In March 1946, among the first investigations at Project RAND, he asked for an engineering analysis of an Earth satellite

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[1] Daniel J. Kevles, *The Physicists* (New York: Vintage Books, 1979), Chapters 19 and 20.

[2] U.S. Army Air Forces, *Third Report of the Commanding General of the Army Air Forces to the Secretary of War*, by General H.H. Arnold, November 12, 1945, p. 68.

[3] Project RAND was contracted to the Douglas Aircraft Company in Santa Monica, California. The acronym is thought by some old-timers to represent Research and Development, and by others, Research for America's National Defense. See Bruce L.R. Smith, *The Rand Corporation: Case Study of a Non-profit Advisory Corporation* (Cambridge, MA: Harvard University Press, 1966), pp. 40-47.

vehicle[4] after learning of a similar investigation at the Navy Bureau of Aeronautics.[5] He wanted the RAND evaluation completed swiftly, in time to match the Navy presentation scheduled for the next meeting of the War Department's Aeronautical Board.[6] Representatives of the Army Air Forces and the Navy presented their preliminary findings at a May 15, 1946, meeting of the board's Research and Development Committee. Although RAND engineers ruled out the satellite as a weapons carrier, they claimed for it a number of important military support functions, including meteorological observation of cloud patterns and short-range weather forecasting, strategic reconnaissance, and the relaying of military communications.[7] [II-2] The Navy representatives likewise emphasized using Earth satellites in defense support applications: for fleet communications and as a navigation platform from which to guide missiles and pilotless aircraft.[8] The military members, however, could not agree on a joint satellite program or confirm that these uses of an Earth satellite would justify the anticipated costs of building, launching, and operating such a vehicle.

Studies of automatic Earth satellites continued at RAND and the Navy Bureau of Aeronautics while the post-war armed services jockeyed for position in a sweeping military reorganization. President Truman signed the National Security Act on July 26, 1947, that created the National Military Establishment and separate military departments of the Army, Navy, and Air Force. Beginning in September 1947, the three service secretaries reported to a new cabinet officer, the Secretary of Defense. But the reorganization did not immediately assign to any of the military services responsibility for new weapons. A newly formed Research and Development Board in the Department of Defense postponed any decisions of service jurisdiction over deployment or control of intermediate range and intercontinental ballistic missiles—rockets that would be required to propel human-made satellites into Earth orbit.[9]

The Research and Development Board inherited supervision of the satellite studies in the Defense Department, and assigned them in December 1947 to its Committee on Guided Missiles. This committee, in turn, formed a Technical Evaluation Group composed of civilian scientists to evaluate the Navy and Air Force programs and recommend a preferred course of action. Chaired by Walter MacNair of Bell Laboratories, on March 29, 1948, the group delivered its findings and recommendation. The members judged the technical feasibility of an Earth satellite to be clearly established; they concluded, however, that neither service had as yet established a military or scientific utility commensurate with the vehicle's anticipated costs. Consequently, the group recommended deferring construction of Earth satellites and consolidating all further studies of their use at RAND.[10] Adopted

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[4] Curtis E. LeMay with Mackinlay Kantor, *Mission with LeMay: My Story* (Garden City, NY: Doubleday & Co., 1965), pp. 399-400.

[5] R. Cargill Hall, "Earth Satellites, A First Look by the United States Navy," in R. Cargill Hall, ed., *History of Rocketry and Astronautics: Proceedings of the Third through the Sixth History Symposia of the International Academy of Astronautics* (San Diego: Univelt, Inc., 1986), AAS History Series, Vol. 7, Part II, pp. 253-278.

[6] The Aeronautical Board, formed during World War I and eventually made up of ranking military members of the Army and Navy air arms, reviewed aeronautical developments and attempted to reconcile "the viewpoints of the two services for the mutual benefit of aviation." The Earth satellite proposals passed from the Aeronautical Board to the War Department's Joint Research and Development Board (JRDB) in early 1947 and, in late 1947, to the JRDB's successor, the Research and Development Board (RDB). Civilian scientists directed and were well represented on the JRDB and RDB, which evaluated and approved all missile and aeronautical research and development within the military departments, and attempted, often without success, to prevent duplication of effort.

[7] Douglas Aircraft Company, Inc.,"Preliminary Design of an Experimental World-Circling Spaceship," Report No. SM-11827, May 2, 1946, copy in NASA Historical Reference Collection, NASA History Office, NASA Headquarters, Washington, DC.

[8] Research and Development Committee, Aeronautical Board, Case No. 244, Report No. 1, May 15, 1946, pp. 1-2, Archives, Jet Propulsion Laboratory, Pasadena, CA.

[9] Charles S. Maier, introduction to *A Scientist at the White House: The Private Diary of President Eisenhower's Special Assistant for Science and Technology*, by George B. Kistiakowsky (Cambridge, MA: Harvard University Press, 1976), pp. xxxiii-xxxiv, also pp. 95-96; Max Rosenberg, *The Air Force and the National Guided Missile Program, 1944-1950* (Washington, DC: Air Force Historical Division Liaison Office, 1964), pp. 22, 63, 84-85.

[10] "Satellite Vehicle Program," Technical Evaluation Group, Committee on Guided Missiles, RDB, GM 13/7, MEG 24/1, March 29, 1948, NASA Historical Reference Collection.

by the Research and Development Board, these recommendations ended Navy satellite work for a number of years and focused the study of military satellites at RAND's headquarters on the West Coast, in Santa Monica, California.[11]

RAND's Earth satellite work in the late 1940s and early 1950s embraced system and subsystem engineering design, the preparation of equipment specifications, and studies of military uses. [II-5] It attracted a host of uncommonly able individuals, among them James Lipp, Robert Salter, Merton Davies, Amron Katz, Edward Stearns, William Kellogg, Louis Ridenour, Francis Clauser, and Eugene Root. Luminaries from academe, such as Bernard Brodie and Harold Lasswell of Yale University and Ansley Coale of Princeton, participated in special conferences, such as the one held at RAND in 1949 that surveyed the prospective political and psychological effects of Earth satellites.[12] All of these men had a hand in shaping the formative space program. And all of them could agree by the early 1950s that the most valuable, first-priority use of a satellite vehicle involved one strategic application: a platform from which to observe and record activity on the Earth.

Back in November 1945, with nuclear weapons and jet aircraft at hand, General Arnold concluded that the next war would provide the country little opportunity to mobilize, much less rearm or train reserves. [II-1] The United States could not again afford an intelligence failure like the one at Pearl Harbor; it could not again be caught unaware in another surprise attack. In the future, he had cautioned Secretary of War Patterson, "continuous knowledge of potential enemies," including all facets of their "political, social, industrial, scientific and military life" would be necessary "to provide warning of impending danger." Arnold also stated, "the targets of the future may be very large or extremely small—such as sites for launching guided missiles." Identifying them, like advance warning, also required "exact intelligence information."[13]

The extreme secrecy that cloaked events within the Soviet Union promoted the focus on intelligence gathering. When relations between the United States and the U.S.S.R. soured after World War II, little information about contemporary Soviet military capabilities existed in the West. In the absence of hard facts in the late 1940s, U.S. leaders acted on their perception of a "growing intent toward expansion and aggression on the part of the Soviet Union."[14] Shortly after the Soviets detonated an atomic bomb in 1949, the newly formed Board of National Intelligence Estimates in the Central Intelligence Agency (CIA)

11. In 1948 Project Rand reorganized as a non-profit advisory group, The Rand Corporation. In Washington, the Defense Department's Research and Development Board continued fitfully to operate until the fall of 1953 when its functions were subsumed in a new Office of Assistant Secretary of Defense for Research and Development; President Dwight D. Eisenhower appointed its first occupant: Donald A. Quarles.

12. Rand Research Memorandum, RM-120, "Conference on Methods for Studying the Psychological Effects of Unconventional Weapons," January 26-28, 1949; Paul Kecskemeti, RM-567, "The Satellite Rocket Vehicle: Political and Psychological Problems," October 4, 1950, both in Rand Library, Santa Monica, CA; see also R. Cargill Hall, "Early U.S. Satellite Proposals," *Technology and Culture* 4 (Fall 1963): 430-31.

Five months after an atomic bomb fell on Hiroshima, Japan, Louis Ridenour provided the American public a first, sobering assessment of future international atomic warfare conducted with Earth-mines and Earth-orbiting satellites. (In the 1950s, fears of a nuclear/thermonuclear surprise attack would move President Eisenhower to fold Earth satellites into an intelligence system designed to preclude such a catastrophe, and establish policy ensuring that spaceflight operations remained devoted to "peaceful purposes.") See L.N. Ridenour, "Pilot Lights of the Apocalypse," and the editor's introductory comment in *Fortune* 33 (January 1946): 116-17, 219.

Robert Salter contributed one of the first and most prescient surveys of the prospects for manned spaceflight in 1951, although the title he selected for it, doubtless to avoid peer ridicule, belied the subject. See Robert M. Salter, "Engineering Techniques in Relation to Human Travel at Upper Altitudes," *Physics and Medicine of the Upper Atmosphere: A Study of the Aeropause* (Albuquerque: University of New Mexico Press, 1952), pp. 480-487.

13. U.S. Army Air Forces, *Third Report of the Commanding General*, pp. 65-67.

14. Harry R. Borowski, *A Hollow Threat: Strategic Air Power and Containment Before Korea* (Westport, CT: Greenwood Press, 1982), p. 6; see also John Prados, *The Soviet Estimate: U.S. Intelligence Analysis and Russian Military Strength* (New York: The Dial Press, 1982), pp. 6-8, 19. See also the newly declassified CIA Office of Research Estimates and later National Intelligence Estimates at the National Archives, including: Central Intelligence Group, "Soviet Foreign and Military Policy," ORE-1, July 23, 1946; Historical Review Group, CIA, National Archives, Box 1, Folder 1; and Central Intelligence Agency, "The Possibility of Direct Soviet Military Action During 1949," ORE-46-49, May 3, 1949, Historical Review Group, CIA, National Archives, Box 3, Folder 102.

warned of the possibility of a Soviet nuclear surprise attack, albeit a limited one, against the United States. That prospect, underscored by the surprise Korean conflict in June 1950 and the development of thermonuclear devices between 1952 and 1954, haunted the nation's military and civilian leadership.[15]

Among America's leaders in the 1950s, the desire to preclude a nuclear or thermonuclear surprise attack was particularly acute. As Dwight D. Eisenhower's biographer aptly phrased it, they had "Pearl Harbor burned into their souls in a way that younger men, the leaders in the later decades of the Cold War, had not." Certainly this was true of Eisenhower in 1953 when he took the oath of office as president, for the subject completely dominated his thinking about disarmament and relations with the Soviets for the next eight years. Besides seeking ways to prevent a surprise attack, Eisenhower also sought "to lessen, if he could not eliminate, the financial cost and the fear that were the price of the Pearl Harbor mentality."[16] To that end, he could agree entirely with General Arnold's views that continuous knowledge of one's potential adversaries was essential "to provide warning of impending danger." The way to get it, Eisenhower also knew from wartime experience, was through aerial reconnaissance.

To secure hard intelligence about the Soviet Union, the CIA and the Air Force undertook a variety of projects at the beginning of the 1950s. Intelligence officers sifted captured German documents for aerial reconnaissance photographs of the U.S.S.R.; that these photographs dated from the early 1940s suggests the magnitude of the problem facing U.S. planners. The interrogation of German and Japanese prisoners of war returning from forced labor in the Soviet Union between 1949 and 1953 helped shed more light on the status of that country's military and industrial might. The Strategic Air Command began flying aircraft on the periphery of the U.S.S.R. on reconnaissance missions, and obtained considerable information about border installations and defenses. But these missions yielded nothing substantial about the Soviet heartland and the state of its economy, society, or military capabilities and preparations.[17]

Seeking this information, RAND proposed and the Air Force conducted the WS 119L program. Beginning in early January 1956, with the approval of President Eisenhower, Air Force personnel loaded automatic cameras in gondolas suspended beneath large Skyhook weather balloons, and during the next four weeks launched 516 of these vehicles in Western Europe. The balloons, equipped with radio beacons that allowed tracking, drifted on prevailing winds at high altitudes eastward across the Eurasian continent, through Soviet airspace. Under the terms of international law to which the United States was a party, the balloons clearly violated Soviet national sovereignty. Those that succeeded in crossing released their gondolas on parachutes, which were recovered in mid-air by C-119 cargo aircraft near Japan and Alaska.[18] Because the aerial path of the balloons could not be controlled, however, the pictures might as easily be of cloud cover or a Siberian forest as of a factory or an airfield. This program, which produced limited intelligence and strongly worded Soviet protests, was quietly canceled on February 6, 1956, at the president's direction. Although the Air Force would subsequently launch a few more of these balloons that operated at yet higher altitudes, Eisenhower quickly terminated that effort as well. Meanwhile, other, more promising avenues of gathering information had appeared.[19]

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[15] James R. Killian, Jr., *Sputnik, Scientists, and Eisenhower: A Memoir of the First Special Assistant to the President for Science and Technology* (Cambridge, MA: The MIT Press, 1977), pp. 68, 94; Prados, *The Soviet Estimate*, p. 21. U.S. intelligence was caught almost completely unaware of the development of the Soviet hydrogen bomb. See, for example, "Estimate of the Effects of the Soviet Possession of the Atomic Bomb Upon the Security of the United States and Upon the Probabilities of Direct Soviet Military Action," ORE 91-49, April 6, 1950, Historical Review Group, CIA, National Archives, Box 4, Folder 131, p. 11.

[16] Stephen E. Ambrose, *Eisenhower: Volume II, The President* (New York: Simon and Schuster, 1984), p. 257. The president's decision in favor of aerial reconnaissance is explained on pp. 258-59.

[17] David A. Rosenberg, "The Origins of Overkill: Nuclear Weapons and American Strategy, 1945-1960," *International Security* 7 (Spring 1983): 20-21; Prados, *The Soviet Estimate*, pp. 57-58.

[18] In the event aerial retrieval failed, the gondolas were designed to float on the ocean's surface and radiate a signal for twenty-four hours. Although many of the gondolas came down in the Soviet Union, sixty-seven of them actually reached the recovery area; of these, the Air Force retrieved forty-four.

[19] Tom D. Crouch, *The Eagle Aloft: Two Centuries of the Balloon in America* (Washington, DC: Smithsonian Institution Press, 1983), pp. 644-49; Ambrose, *Eisenhower, Vol. II*, pp. 309-11; Killian, *Sputnik, Scientists, and*

Research and Initial Development

While the CIA and the Air Force endeavored to gather information about the Soviet Union from any source, the Department of Defense acted on the issue of military roles and missions. On March 21, 1950, Secretary of Defense Louis Johnson assigned the Air Force responsibility for long-range strategic missiles, including ICBMs. A few weeks later, the Research and Development Board vested jurisdiction for military satellites in the same service. With these responsibilities, Air Force leaders directed RAND to complete studies of a military Earth satellite.[20]

The resultant RAND report, issued in April 1951, described a spacecraft fully stabilized on three axes and that employed a television camera to scan the Earth and transmit the images to receiving stations. [II-3] The television coverage thus acquired, RAND reminded the service had to occur when "weather permits ground observation."[21] The RAND report encouraged Air Force leaders to believe that directed, periodic observation of the Soviet Union might soon be conducted from extremely high altitudes. To confirm these findings, on December 19, 1951, Air Force headquarters authorized the firm to subcontract for detailed spacecraft subsystem studies. A few weeks later, in January 1952, the service convened a seminal "Beacon Hill" study group to assay strategic aerial reconnaissance under the auspices of Project Lincoln at the Massachusetts Institute of Technology.[22]

The Beacon Hill study group, which first met between January 7 and February 15, 1952, considered improvements in Air Force aerial intelligence processing, sensors, and vehicles. Chaired by Carl Overhage of Eastman Kodak, the fifteen-member group included Air Force optics specialist Lieutenant Colonel Richard Leghorn (later, the founder of Itek), James Baker of the Harvard Observatory, Edwin Land (the founder of Polaroid), Stuart Miller of Bell Labs, Richard Perkin (co-founder of Perkin-Elmer), scientific consultant Louis Ridenour, Allen Donovan of Cornell Aeronautical Labs, and Edward Purcell of Harvard University. These individuals concluded their deliberations in May and issued a final report in June 1952.

The Beacon Hill report recommended to the Air Force specific improvements in the orientation, emphasis, and priority assigned to strategic intelligence, and solutions to the problems involved in its collection, reduction, and use. The study group also suggested refinements in sensors. The improved sensors, the group advised, could be flown near Soviet territory in advanced high-altitude aircraft, high-altitude balloons (later, WS 119L), sounding rockets, and long-range drones such as the Snark or Navaho air-breathing missiles. Whatever the choice of vehicles, study group participants cautioned the service that actual "intrusion" over Soviet territory and violation of its national sovereignty required approval of political authorities "at the highest level." Space satellites, mentioned only in passing and then only as vehicles of the future in the grip of Newtonian mechanics, were, however, identified as certain intruders that would have to "overfly" the Soviet Union.[23]

Eisenhower, p. 12; Paul E. Worthman recollections, cited by W. W. Rostow in *Open Skies: Eisenhower's Proposal of July 21, 1955* (Austin: University of Texas Press, 1982), pp. 189-94. Project "Moby Dick," the test of WS 119L, was conducted in the United States during 1952-1955 and accounted for numerous UFO sightings—as did later tests of the U-2 and A-12.

[20] Enclosure with recommendations for guided missiles to Memo 1620/17, for Secretary of Defense Louis Johnson, from the Joint Chiefs of Staff, March 15, 1950; Memo for the Joint Chiefs of Staff from Louis Johnson, "Department of Defense Guided Missiles Program," approving recommendations, March 21, 1950; Report, Air Research and Development Command, *Space System Development Plan*, WDPP-59-11, January 30, 1959, Tab I, "Background," p. I-1-1, all in NASA Historical Reference Collection.

[21] J.E. Lipp, R.M. Salter, Jr., and R.S. Wehner, "The Utility of a Satellite Vehicle for Reconnaissance," The RAND Corporation, R-217, April 1951, p. 80, Rand Library.

[22] RCA-Rand, "Progress Report (Project Feed Back)," Report RM-999, January 1, 1953, Rand Library. Background of the Beacon Hill study and related developments in 1951 is contained in Herbert F. York and G. Allen Greb, "Strategic Reconnaissance," *Bulletin of the Atomic Scientists*, April 1977, p. 34.

[23] "Beacon Hill Report: Problems of Air Force Intelligence and Reconnaissance," Project Lincoln, Massachusetts Institute of Technology, Boston, MA, June 15, 1951, *passim*, JPL Archives.

Elsewhere around the country, various firms under contract to RAND were designing and evaluating specific satellite equipment, including a television payload (Radio Corporation of America), vehicle guidance and attitude-control devices (North American Aviation), and a nuclear auxiliary electrical power source (Westinghouse Electric Corporation, Bendix Aviation, Allis-Chalmers, and the Vitro Corporation). This effort, known collectively as Project Feed Back, confirmed that automated satellites could be built without exceptional delays and at an affordable cost. Whatever the legal ramifications of overflight in outer space might be, in September 1953, RAND officials recommended that a satellite be built.[24] [II-4] A few months later, they concluded their preliminary work and published a final report.

Issued on March 1, 1954, the Project Feed Back report described a military satellite for observation, mapping, and weather analysis, along with examples of the necessary space hardware and ground support systems. [II-6] The second stage booster-satellite would be placed in a low-altitude, "sun synchronous" polar orbit inclined 83 degrees to the equator. Launched at the proper time of day at this inclination, the satellite would precess in one year through 360 degrees, allowing a television camera to operate in maximum daylight brightness throughout all seasons.[25] RAND engineers estimated this satellite system would produce "30 million pictures in one year of operation," a sum equivalent to all the pictures held in the USAF Photo Records and Services Division acquired from all sources in peace and war over the previous twenty-five years![26] Where the Air Force might find the photo-interpreters needed to evaluate this mountain of information, RAND did not say.

In early 1954, however, the problem that faced U.S. policy-makers was not too much intelligence information about the Soviet Union, but far too little. Attempts to fly around the U.S.S.R. had thus far produced inadequate information; details of Soviet military preparations and capabilities remained as much an enigma as ever. Continued Soviet production of atomic weapons, and the means to deliver them, such as the Bison long-range bomber, combined in August 1953 with the Soviet detonation of a thermonuclear device, particularly disturbed President Eisenhower. Former Supreme Commander of the Allied Expeditionary Force in Western Europe, Eisenhower had helped engineer the destruction of the Axis powers in World War II and knew firsthand the enormous devastation that accompanied modern total war.

Any aerial surprise attack on the United States with nuclear weapons, even a limited one, could lay waste to most of the metropolitan areas on the East and West coasts. Moreover, with government agencies unable to gauge the exact nature and extent of a Soviet military threat, the president found himself at a distinct disadvantage in selecting the appropriate level of military preparedness to combat it. This situation, Eisenhower made clear at a meeting of his National Security Council on February 24, 1954, had to be resolved—and soon. As a first step to counter a possible surprise attack, he had already approved a prior council recommendation to design and construct, with Canadian approval, a Distant Early Warning (DEW) picket line of radars across the North American Arctic, to detect and track any Soviet bombers that might be directed against the two countries.[27]

Civilian scientists appointed to the Science Advisory Committee in the Office of Defense Mobilization, meanwhile, had been examining similar issues under the prodding of

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[24] Perry, *Origins of the USAF Space Program*, pp. 35, 39; and Merton E. Davies and William R. Harris, *RAND's Role in the Evolution of Balloon and Satellite Observation Systems and Related U.S. Space Technology* (Santa Monica, CA: The RAND Corporation, 1988), p. 47.

[25] J.E. Lipp & R.M. Salter, "Project Feed Back Summary Report," The RAND Corporation, R-262, Volume II, March, 1954, pp. 109-10, Rand Library.

[26] *Ibid.*, pp. 85-86.

[27] Stephen E. Ambrose, *Ike's Spies: Eisenhower and the Espionage Establishment* (Garden City, NY: Doubleday & Co., 1981), pp. 253, 267; Rpt., Aerospace Defense Command, *A Chronology of Air Defense, 1914-1972*, ADC Historical Study No. 19, March 1973, p. 33; see also NSC 159/4 and attached statement of policy on "Continental Defense," September 25, 1953, and NSC 5408, "Report to the National Security Council by the National Security Planning Board," February 11, 1954, as reprinted in William Z. Slany, ed., *Foreign Relations of the United States, 1952-1954, Volume II: National Security Affairs, Part 1* (Washington, DC: U.S. Government Printing Office, 1984), pp. 475-89, 609-24.

Trevor Gardner, the "technologically evangelical assistant secretary of the Air Force for research and development." Learning of these studies, the president's special assistant for security affairs, General Robert Cutler, invited key committee members to the White House. Meeting with them on March 27, 1954, Eisenhower discussed his concerns about a surprise attack on the United States and the prospects for avoiding or containing it. "Modern weapons," he warned, "had made it easier for a hostile nation with a closed society to plan an attack in secrecy and thus gain an advantage denied to the nation with an open society." In spite of the Oppenheimer case, he apparently viewed the scientists as honest brokers in a partisan city, and he challenged them to tackle this problem.[28]

They did. Lee A. DuBridge, president of the California Institute of Technology and chair of the Science Advisory Committee, and James R. Killian, Jr., president of the Massachusetts Institute of Technology, formed a special task force to consider three areas of national security: continental defense, strike forces, and intelligence, with supporting studies in communications and technical manpower. Approved by President Eisenhower in the spring, the Surprise Attack Panel, or the Technological Capabilities Panel (TCP) as it was subsequently renamed, chaired by Killian, conducted its work between August 1954 and January 1955. Its membership included most of those who had produced the Beacon Hill Report and represented the best that American science and engineering offered. The panel's extraordinary two-volume report, *Meeting the Threat of Surprise Attack*, was issued on February 14, 1955. By all published accounts, the report affected the course of national security affairs enormously.[29]

The TCP report resulted in a number of significant alterations in U.S. defense preparedness. Among other things, it recommended accelerating procurement of intercontinental ballistic missiles (Atlas, and later Titan and Minuteman ICBMs), constructing land- and sea-based intermediate-range ballistic missiles (later Thor, Jupiter, and Polaris IRBMs), and speeding construction of the DEW line in the Arctic (declared operational in August 1957). The TCP also identified a timetable of changes in the relative military and technical positions of the two superpowers. Even more important, perhaps, were the recommendations to acquire and use strategic pre-hostilities intelligence. The intelligence panel, chaired by Edwin Land, urged construction and deployment of the U-2 aircraft[30] that could, if called upon, overfly the Soviet Union at very high altitudes.[31] Any mention of the U-2, however, was excluded from the report proper. In its section on intelligence applications

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[28] The description of Gardner, and Eisenhower as quoted, in Killian, *Sputnik, Scientists, and Eisenhower*, p. 68; see also, Prados, *The Soviet Estimate*, p. 60.

[29] *Meeting the Threat of Surprise Attack*, Vol I and Vol II, February 14, 1955, JPL Archives; see also Killian, *Sputnik, Scientists, and Eisenhower*, pp. 11-12, 70-82; Herbert F. York and G. Allen Greb, "Military Research and Development: A Postwar History," *Bulletin of the Atomic Scientists*, January 1977, p. 22; also York and Greb, "Strategic Reconnaissance," p. 35. For the next two years, the deliberations of the National Security Council turned frequently to the findings and recommendations contained in this report. See John P. Glennon, ed., *Foreign Relations of the United States, 1955-1957: Volume XIX, National Security Policy* (Washington, DC: U.S. Government Printing Office, 1990), hereafter referred to as *Volume XIX*.

[30] Eisenhower approved development of the U-2 during the TCP deliberations, on November 24, 1954, and assigned the project to the CIA instead of the Air Force. Under the guidance of Richard M. Bissell, Jr., CIA Special Assistant to the Director of Central Intelligence, Colonel O. J. Ritland, USAF, and Clarence L. "Kelly" Johnson of the Lockheed Aircraft Corporation, the first U-2 was airborne within eight months, on August 6, 1955. Ambrose, *Ike's Spies*, p. 268; Leonard Mosley, *Dulles: A Biography of Eleanor, Allen, and John Foster Dulles and Their Family Network* (New York: Dial Press, 1978), pp. 365-66.

[31] Dwight D. Eisenhower, *Waging Peace, 1956-1961* (Garden City, NY: Doubleday & Co., Inc., 1965), p. 470; Killian, *Sputnik, Scientists, and Eisenhower*, pp. 71-84; Rpt., *A Chronology of Air Defense, 1914-1972*, p. 46. The cleared recommendations of the TCP are reprinted in *Volume XIX*, pp. 46-56.

Throughout the 1950s Eisenhower withheld knowledge of the U-2's existence from all but those few directly involved. The program never appeared as an item in National Security Council deliberations until "it tore its britches" in 1960. Karl G. Harr, Jr., "Eisenhower's Approach to National Security Decision Making," in Kenneth W. Thompson, ed., *The Eisenhower Presidency: Eleven Intimate Perspectives of Dwight D. Eisenhower*, Vol. 3 in *Portraits of American Presidents* (Lanham, MD: University Press of America, 1984), p. 97. The product of the U-2 flights was even more closely held, and Eisenhower refused to refute political charges that an American "bomber gap" and, later, a "missile gap" existed, even though he knew them to be false. The latter issue, artfully exploited by John Kennedy, may well have cost Richard Nixon the 1960 presidential election. Since that time, to avoid an unwanted repetition, candidates have been "briefed" on national security affairs before a presidential campaign begins. All of these events square with the perceptive thesis of Eisenhower governance elucidated by Fred I. Greenstein, *The Hidden-Hand Presidency: Eisenhower as Leader* (New York: Basic Books, Inc., 1982).

of science, the report recommended beginning immediately a program to develop a small scientific satellite that would operate at extreme altitudes above national airspace, intended to establish the principle of "freedom of space" in international law for subsequent military satellites.[32] Although committee members could hope that scientific satellites might set such a precedent, James Killian, who chaired the TCP, viewed RAND's proposed military observation satellite as a "peripheral project" and would refuse to support it until the Soviets launched Sputnik I nearly three years later.

Back in the summer of 1954, shortly after authorizing the surprise-attack study, President Eisenhower approved the formation of an organization devoted exclusively to that subject: the National Indications Center. This center, chaired by the Deputy Director of Central Intelligence and composed of specialists drawn from U.S. intelligence agencies, and the Departments of Defense and State, formed the interagency staff of the National Watch Committee, which consisted of presidential confidants such as the Secretaries of State and Defense, and the Director of Central Intelligence (DCI). Chartered on July 1, 1954, for the express purpose of "preventing strategic surprise," the center drew on information furnished by all national intelligence organizations. Eisenhower, one of the participants recalled vividly, was a man "boresighted on early warning of surprise attack."[33]

The National Indications Center assessed the military, economic, and social demands involved in mounting a surprise attack and issued a weekly "watch report" to the Watch Committee members. Staffers expanded a list of key indicators developed earlier under the direction of James J. Hitchcock in the CIA, and applied it to developments that would presage surprise attack in the nuclear age.[34] That is, presuming rational political leadership, one state intending to attack another would need to prepare carefully, say, by dispersing its industry and population many months in advance, and by deploying its military forces on land and sea just days or hours before "M-Day." Thus, the proper intelligence "indicators" applied against this matrix would yield readily identifiable signals, much like a traffic light: green—normal activity; amber—caution; and red—warning.[35] These strategic warning indicators, eventually linked to "defense conditions" (DEFCON 5 through 1), enabled U.S. leaders to mobilize resources and establish force readiness postures. The military, economic, and technical indicators listed in this matrix successfully predicted the Suez War in 1956, and have been monitored and reported in one form or another to the president and other command authorities ever since. The National Indications Center itself, however, was dissolved in March 1975.[36]

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[32] *Meeting the Threat of Surprise Attack,* Vol. II, pp. 146-48; Memo for the Record, L. B. Kirkpatrick, "Meeting with the President's Board of Consultants, Saturday, 28 Sep. 1957, 11 a.m to 2 p.m.," Eisenhower Library, Abilene, KS.

[33] Interview with James J. Hitchcock, May 23, 1986; Cynthia M. Grabo, "The Watch Committee and the National Indications Center: The Evolution of U.S. Strategic Warning, 1950-1975," *International Journal of Intelligence and CounterIntelligence* 3 (Fall 1989): 369-70; see also Eisenhower letter to Winston Churchill, cited in Killian, *Sputnik, Scientists, and Eisenhower,* p. 88. One has only to peruse the documents in *Volume XIX* to gain an appreciation for Eisenhower's fixation on surprise attack and his dedication to forestalling such an event. See especially [8] at p. 40.

[34] A RAND study doubtless figured in these deliberations and actions, though a direct linkage is not established at this time. One year earlier, three months after President Eisenhower's inauguration, Andrew W. Marshall and James F. Digby issued RAND Special Memorandum SM-14, *The Military Value of Advanced Warning of Hostilities and its Implications for Intelligence Indicators,* April 1953 (rev. July 1953). The authors compared intelligence warning of attack to the performance of military forces, and urged attention to short-term indications of Soviet preparations for surprise attack. Copies unquestionably circulated within intelligence circles, including the CIA.

[35] The British first developed an indicators list in 1948 to identify actions the Soviets would have to take to occupy Berlin. Hitchcock subsequently altered and expanded the list at the CIA in the late 1940s and early 1950s to identify actions that would warn of a surprise attack against the United States. The best available source in the open literature that describes related RAND activities in the 1940s and 1950s is Davies and Harris, *RAND's Role in the Evolution of Balloon and Satellite Observation Systems and Related U.S. Space Technology.*

[36] Grabo, "The Watch Committee and the National Indications Center," p. 384; *Volume XIX* [19]; another survey of this subject in the open literature is Duncan E. MacDonald, "The Requirements for Information and Systems," in F. J. Ossenbeck and P. C. Kroeck, eds., *Open Space and Peace: A Symposium on the Effects of Observation* (Stanford, CA: The Hoover Institution, 1964), pp. 64-83. The NSC Planning Board, also at the president's direction, in November 1954 had established a "net capabilities evaluation subcommittee" that performed a function similar to the National Indications Center for the council. See [1 and 19] in *Volume XIX.*

Establishing National Space Policy

President Eisenhower, to be sure, worried considerably about the danger of a Soviet surprise attack in the mid-1950s, and judged strategic warning absolutely vital to counter or preclude it. Shortly after the TCP submitted its report to the National Security Council, in the spring of 1955 the president's closest advisors determined, if at all possible, to keep outer space a region open to all, where the spacecraft of any state might overfly all states, a region free of military posturing. By adopting a policy that favored a legal regime for outer space analogous to that of the high seas, the United States might make possible the precedent of "freedom of space" with all that implied for overflight. This choice also favored non-aggressive, peaceful spaceflight operations, especially the launch of scientific Earth satellites to explore outer space that civilian scientists now urged as part of the U.S. contribution to the International Geophysical Year (IGY).[37] [II-8, II-11] This program, proposed by the U.S. National Committee for the IGY of the National Academy of Sciences in a March 14, 1955, report, had been approved by the academy and sent to National Science Foundation director Alan T. Waterman for government consideration.[38] [II-9]

By this time, a number of prominent scientists and military leaders actively sought approval for spaceflight missions. A few months after RAND's Feed Back report appeared, the Air Force had acted on its recommendations. On November 29, 1954, the Air Research and Development Command issued System Requirement No. 5, which called for competitive system-design studies of a military satellite. On March 16, 1955, while the National Academy of Sciences was completing its satellite deliberations, the USAF issued General Operational Requirement No. 80 (SA-2c), which approved construction of and provided technical requirements for military observation satellites. At the same time, the service named this observation satellite the WS 117L program. In April, the Naval Research Laboratory submitted to the Defense Department a "Scientific Satellite Program" for the IGY, eventually known as Vanguard, which proposed using as a first-stage booster the Viking sounding rocket. Meanwhile, the Army's Redstone rocket team led by Major General John B. Medaris and Wernher von Braun had for some months urged a small, inert Earth satellite launched with the Jupiter IRBM, called Project Orbiter (later named Explorer). [II-7] These and other events soon to follow made 1955 the most momentous of years for the fledgling U.S. space program.[39]

In May 1955, administration officials agreed that the country should launch scientific Earth satellites as a contribution to the IGY. In early May, Assistant Secretary of Defense for Research and Development Donald Quarles referred the Army and Navy IGY satellite proposals to his Committee on Special Capabilities, and requested a scientific

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37. In 1952 the International Council of Scientific Unions (ICSU) established a committee to arrange another International Polar Year to study geophysical phenomena in remote areas of the Earth (two previous polar years had been conducted, one in 1882-1883 and another in 1932-1933). Late in 1952 the council expanded the scope of this effort, planned for 1957-1958, to include rocket research in the upper atmosphere and changed the name to the International Geophysical Year. In October 1954 the ICSU, meeting in Rome, Italy, adopted another resolution that called for launching scientific Earth satellites during the IGY. "Editorial Note," in John P. Glennon, ed., *Foreign Relations of the United States, 1955-1957: Volume XI, United Nations and General International Matters* (Washington DC: U.S. Government Printing Office, 1988), [361], pp. 784-85.

38. A few months earlier, in December 1954, the American Rocket Society's Committee on Space Flight completed a similar report on the utility of scientific Earth satellites, including a proposal by John Robinson Pierce of Bell Laboratories for a passive communication satellite that much resembled the later Project Echo, and submitted it to National Science Foundation Director Alan T. Waterman. By the spring of 1955 a number of Earth-satellite proposals had landed on the desks of officials at the National Science Foundation and the Department of Defense. See R. Cargill Hall, "Origins and Development of the Vanguard and Explorer Satellite Programs," *Airpower Historian* 9 (October 1964): 106-108.

39. *Ibid.*, pp. 102-104. Project Orbiter first appeared with the name "A Minimum Satellite Vehicle," the result of an August 3, 1954, meeting between Army officials at the Redstone Arsenal and Navy representatives from the Office of Naval Research. See Dr. Wernher von Braun, "A Minimum Satellite Vehicle: Based on components available from missile developments of the Army Ordnance Corps," September 15, 1954, NASA Historical Reference Collection.

satellite proposal from the Air Force.[40] He instructed committee members to evaluate these proposals and recommend a preferred program. Quarles, who warmly embraced the satellite recommendations of Killian's Technological Capabilities Panel and urged an IGY satellite program, subsequently drafted a policy for the launching of these and other spacecraft and submitted it on May 20 to the National Security Council (NSC). NSC members meeting on May 26 endorsed the Quarles' proposal and accompanying national policy guidance. A scientific satellite program for the IGY would not interfere with development of high-priority ICBM and IRBM weapons. Emphasis would be placed on the peaceful purposes of the endeavor. The scientific satellites would help establish the principle in international law of "freedom of space" and the right of unimpeded overflight that went with it, and these IGY satellites would serve as technical precursors for subsequent U.S. military satellites. "Considerable prestige and psychological benefits," the policy concluded, "will accrue to the nation which first is successful in launching a satellite."[41] The next day, "after sleeping on it," President Eisenhower approved this plan.[42] [II-10]

With the president's decision, the United States had tentatively set out to prosecute two closely associated space programs: instrumented military applications and civilian scientific satellites. Presidential advisors still perceived the more complex military spacecraft to be a long way off, but the IGY scientific satellite program was clearly identified as a stalking horse to establish the precedent of overflight in space for the eventual operation of military reconnaissance satellites. Charged with the WS 117L program, the Air Force earlier in 1955 had selected three firms to compete in a one-year design study of a preferred vehicle. Neither the military nor the scientific satellite program had selected a contractor to conduct the work, and neither shared a national priority.

In Burbank, California, in Kelly Johnson's Lockheed "skunk works," the U-2 project unquestionably claimed the highest of national priorities. With the first of these turbojet-powered gliders nearing completion, Eisenhower learned that the United States could soon overfly parts of Soviet airspace at will.[43] The U-2 had an anticipated operating ceiling in excess of 70,000 feet. No known jet fighter operated at altitudes above 50,000 feet. But however safe piloted aerial overflight, or however attractive this opportunity to acquire intelligence on Soviet military preparations, might be, any unauthorized penetration of another state's airspace represented a clear violation of international law—a violation, that is, unless the leaders concerned agreed to such flights beforehand.

While the U-2 neared its first test flight in Nevada, on July 21, 1955, at a summit conference in Geneva, Eisenhower advised Soviet leaders of just such a plan. The president, in an unannounced addition to a disarmament proposal, directly addressed the subject that most concerned him. The absence of trust and the presence of "terrible weapons" among states, he asserted, provoked in the world "fears and dangers of surprise attack." To eliminate these fears, he urged that the Soviet Union and the United States provide "facili-

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[40] The Air Force proposal, called "World Series," featured an Atlas first stage and Aerobee-Hi second stage; it was submitted to the Committee on Special Capabilities (Stewart Committee) during the first week of July 1955. Because World Series conflicted with the WS 117L program, Air Force leaders gave it scant support.

Throughout the Eisenhower presidency until his death in office, Donald A. Quarles would influence greatly the choice of policy and missions for the civilian and military satellite programs, first as Assistant Secretary of Defense for Research and Development (September 1953 to August 1955), then as Secretary of the Air Force (August 1955 to April 1957), and finally as Deputy Secretary of Defense (April 1957 to May 1959).

[41] National Security Council, NSC 5520, "Draft Statement of Policy on U.S. Scientific Satellite Program," May 20, 1955, pp. 1-3. See also Annex B, accompanying Memorandum from Nelson A. Rockefeller to Mr. James S. Lay, Jr., Executive Secretary, "U.S. Scientific Satellite Program," May 17, 1955. These documents reprinted, along with the NSC endorsement, in John P. Glennon, ed., *Foreign Relations of the United States, 1955-1957: Volume XI, United Nations and General International Matters* (Washington DC: U.S. Government Printing Office, 1988), [340/341], pp. 723-33, hereafter referred to as *Volume XI*. Air Force leaders enthusiastically embraced the dictum that IGY satellites would not interfere with the ICBM, IRBM, and military satellite programs; Perry, *Origins of the USAF Space Program*, pp. 43-44.

[42] Eisenhower quoted in Lee Bowen, *An Air Force History of Space Activities, 1945-1959* (USAF Historical Division Liaison Office, August 1964), p. 64. Eisenhower did approve the IGY satellite program in NSC 5520 the next day, on May 27, 1955; see *Volume XI* [341], p. 733.

[43] Ambrose, *Ike's Spies*, p. 271; Clarence "Kelly" Johnson, interview with Morley Safer on CBS "60 Minutes," October 17, 1982; Eisenhower, *Waging Peace*, pp. 544-45.

ties for aerial photography to the other country" and conduct mutually supervised reconnaissance overflights.[44] Before the day ended, the Chair of the Soviet Council of Ministers, Nikolai Bulganin, and First Secretary of the Communist Party Nikita Khrushchev privately rejected the president's plan, known eventually as the "Open Skies" doctrine, as an obvious U.S. attempt to "accumulate target information." "We knew the Soviets wouldn't accept it," Eisenhower later confided in an interview, "but we took a look and thought it was a good move."[45] Though the Soviets might object, they were forewarned.[46] Eleven months later, some five months after he terminated the balloon reconnaissance program, Eisenhower approved the first U-2 overflight of the U.S.S.R.[47]

Back in the United States, late in the evening of July 25, 1955, Eisenhower informed the nation in a radio address of the results of the summit conference. On July 27, Eisenhower met with National Science Foundation Director Waterman, Assistant Secretary of Defense Quarles, and Undersecretary of State Herbert Hoover, Jr., to discuss how best to make known the existence of a U.S. IGY satellite program. A general statement, it was decided, would come from the White House after congressional leaders had been notified. These statements would emphasize the satellite project "as a contribution benefiting science throughout the world," and would not link it in any way "to military missile development." Two days later, on July 29, 1955, the president publicly announced plans for launching "small unmanned, Earth circling satellites as part of the U.S. participation in the International Geophysical Year" scheduled between July 1957 and December 1958. [I-17] His statement avoided any hint at the underlying purpose of the enterprise, and assigned to the National Science Foundation responsibility for directing the project, with "logistic and technical support" to be furnished by the Department of Defense. Donald Quarles' Committee on Special Capabilities in early August selected for the IGY satellite project the Naval Research Laboratory's Vanguard proposal, one that combined modified Viking and Aerobee-Hi sounding rockets for the scientific satellite booster, and placed the U.S. Navy in charge of logistics and technical support.[48]

In June 1956, the Air Force chose Lockheed's Missile Systems Division in Sunnyvale, California, to design and build the military satellites for the WS 117L program. Lockheed's winning proposal featured a large, second-stage booster satellite that could be stabilized in orbit on three axes with a high pointing accuracy. To become known as "Agena," this vehicle would be designed and tested to meet Air Force plans for an operational capability in the third quarter of 1963. While the diminutive Vanguard scientific satellite was projected to weigh tens of pounds and be launched by a modified sounding rocket, the

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[44] "Statement on Disarmament, July 21," *The Department of State Bulletin*, 33, No. 841, August 1, 1955, p. 174; Elie Abel, "Eisenhower Calls Upon Soviet Union to Exchange Arms Blueprints," *New York Times*, July 22, 1955, p. 1; also Prados, *The Soviet Estimate*, pp. 31-32. The term "Open Skies" was coined later by the popular press and applied to Eisenhower's statement on disarmament. The background of this proposal, as advanced by the president's special assistant, Harold Stassen, and debated in the National Security Council, is contained in John P. Glennon, ed., *Foreign Relations of the United States, 1955-1957: Volume XX, Regulation of Armaments; Atomic Energy* (Washington, DC: U.S. Government Printing Office, 1990), see especially [33 through 48]. By 1956-1957, Eisenhower and other key administration leaders would view aerial reconnaissance as an "inspection system" that could serve two critical functions: to forewarn of surprise attack *and* supervise and verify arms-reduction and nuclear-test-ban agreements.

[45] Herbert S. Parmet, *Eisenhower and the American Crusades* (New York: The Macmillan Company, 1972), p. 406; see also W. W. Rostow, *Open Skies*, pp. 7-8.

[46] Richard Leghorn, then working for Eisenhower's special assistant Harold Stassen, wrote the paper on which the "Open Skies" doctrine was predicated. He also produced the 32-page booklet explaining this disarmament proposal given to those attending the Big Four Geneva Conference. Richard S. Leghorn, "U.S. Can Photograph Russia from the Air Now," *U.S. News & World Report*, August 5, 1955, pp. 70-75; "Editor's Note" at p. 71. Cleared by the White House, this important article explained the administration's rationale for Open Skies and the implications of this plan for arms reduction.

[47] Ambrose, *Ike's Spies*, pp. 31-34, 266.

[48] Attendees at the July 27 meeting included Eisenhower's staff secretary and defense liaison, Colonel Andrew Goodpaster, U.S. Army. Goodpaster, "Memorandum of Conference with the President, July 27, 1955, 11:45AM." The news release is reprinted in *Volume XX* [342], p. 734; see also for related events and the Quarles' IGY selection process, Constance McL. Green and Milton Lomask, *Vanguard: A History* (Washington DC: NASA SP-4202, 1970), pp. 37-38, 55-56.

proposed Air Force satellite would weigh thousands of pounds and be launched atop an Atlas ICBM.[49]

Among other payloads, Lockheed recommended for development those projects already identified by the Navy and RAND, and added one of its own: an infrared radiometer and telescope to detect the hot exhaust gases emitted by long-range jet bombers and, more important, large rockets as they ascended under power through the atmosphere. This novel aircraft-tracker and missile-detection innovation advanced by Joseph J. Knopow, a young Lockheed engineer, fit nicely into the strategic warning efforts of the day and unquestionably helped tip the scales in Lockheed's favor.[50] The Air Force awarded the firm a contract for this program a few months later, in October 1956.[51]

Thus, a year before Sputnik, the two modest U.S. space programs moved ahead slowly, staying within strict funding limits and avoiding unwanted interference, with development of the nation's long-range ballistic missiles just underway. They shared a lower priority than other high-technology defense department programs. To avoid provoking an international debate over "freedom of space," Eisenhower administration leaders in 1956 restrained government officials from any public discussion of spaceflight.[52] At the Pentagon, after a WS 117L program briefing on November 17, Donald Quarles, now Secretary of the Air Force, instructed Lieutenant General Donald Putt, Deputy Chief of Staff for Research and Development, to cease all efforts toward vehicle construction. He expressly forbade fabrication of a mockup or of the first satellite without his personal permission. A military satellite, the Air Force learned, would under no circumstances precede a scientific satellite into orbit.[53]

In early 1957 President Eisenhower remained undecided whether the United States needed to launch more than six IGY satellites for science. Moreover, Secretary of Defense Charles Wilson remained unimpressed with expensive astronautical ventures of any kind.

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[49] In the mid 1950s, Convair's James W. Crooks, Jr., constantly reminded audiences at Wright-Patterson AFB and elsewhere that the Atlas could lift the weight of a new Chevrolet, 3,500 lbs., into low-Earth orbit. As events turned out, Atlas with a powered upper stage could lift a good deal more—about 10,000 lbs.—into low-Earth orbit.

[50] In time, this payload proposal would be separated and identified as the Missile Detection and Alarm System (MIDAS), then evolve to become the contemporary Defense Support Program (DSP). Today, this remarkable set of military satellites can detect and provide advance warning of a missile attack within moments of a launch at sea or on land.

[51] LMSD 1536, *Pied Piper Development Plan,* Vol II, March 1, 1956, Subsystem Plan, A. Airframe, A-Apdx., pp. 3-4; and Vol. I, System Plan, *passim,* Eisenhower Library.

[52] Unwitting of the National Security Council deliberations and of the ground rules established for the nation's space program, contemporary American military leaders failed entirely to comprehend the rationale that prompted this restriction on public discussion. See, for example, Maj. Gen John B. Medaris, U.S. Army, with Arthur Gordon, *Countdown for Decision* (New York: Paperback Library, Inc., 1960), pp. 101, 124; and testimony of Lt. Gen James M. Gavin, Deputy Chief of Staff Research and Development, U.S. Army, in U.S. Senate, *Inquiry into Satellite and Missile Programs,* "Hearings before the Senate Preparedness Investigating Subcommittee of the Committee on Armed Services," Part II, 6 January 1958, p. 1474, and Part I, 13 December 1957, p. 509. Air Force General Bernard Schriever, charged with the missile and space efforts of that service in the mid-to-late 1950s, was still fuming in 1985. Recalling a February 1957 speech, he announced that the Air Force was ready to "move forward rapidly into space. I received instruction the next day from the Pentagon that I shouldn't use the word 'space' in any of my future speeches. Now that was February 1957! They [the administration] had the IGY going, you know, which was kind of a scientific boondoggle." Richard H. Kohn, June 1985 interview with Generals Doolittle, Schriever, Phillips, Marsh, and Dr. Getting, in Jacob Neufeld, ed., *USAF Research and Development* (Washington, DC: Office of Air Force History, 1990) p. 105. Regarding priority, GOR No. 80 of March 16, 1955, specified a date of "operational availability" for the military satellites in the mid 1960s, a date that bespoke a low priority and bracketed this system to follow the U-2. Certainly, the first military spaceflights would trail by many months those of the scientific satellites. IGY space program priorities considered in "Memorandum of Discussion at the 283d Meeting of the National Security Council, Washington, May 3, 1956," in *Volume XI* [343], pp. 740-41.

[53] *USAF Space Programs, 1945-1962, Volume 1* (USAF Historical Division Liaison Office, October 1962), p. 18. The historian added: "...it was apparent that the possible political repercussions arising from use of a military space vehicle were causing concern." On the West Coast, Schriever complained vigorously. The next year, in 1957, he declared, "I finally got $10 million [for WS 117L] from Don Quarles, who was Secretary of the Air Force, with instructions that we could not use that money in any way except component development. No systems work whatsoever. $10 million!" Schriever comments in *USAF Research and Development,* pp. 105-106. The Quarles' stricture remained in effect for nearly an entire year, and was not lifted until September 1957.

"A 'damn orange' up in the air," he snapped to confidants. In May 1957, as costs to build and launch the original six IGY vehicles soared from an estimated $20 million to $100 million, he told Eisenhower that Earth satellites, whatever their merit, "had too many promoters and no bankers."[54] [II-12] Donald Quarles, named Deputy Secretary of Defense one month earlier, nonetheless supported the U.S. IGY satellite effort while he kept an eye on related developments in the U.S.S.R. At his request near the end of June, CIA Director Allen Dulles assessed recent Soviet hints of an impending satellite launch. "The U.S. [intelligence] community," Dulles advised, "estimates that for prestige and psychological factors, the U.S.S.R. would endeavor to be the first in launching an earth satellite." Moreover, he said, it "probably is capable of launching a satellite in 1957."[55] [II-13] However accurate the CIA assessment might be, advocates of the WS 117L program found themselves unable to secure active support within the administration, and in July the Defense Department imposed sharp spending limits that effectively constrained their work to the "study level."[56]

This state of affairs changed dramatically a few months later, in October-November 1957, after the Soviet Union launched Sputniks I and II. Despite presidential assurances, the Soviet space accomplishments fueled a national debate over U.S. defense and science policies.[57] [II-14, II-15] Having downplayed the space program for purposes of their own, Eisenhower and his advisors underestimated the psychological shock value of the satellites that RAND had identified, the Technological Capabilities Panel had acknowledged, and the National Security Council had underscored just a few years before. What began as an evenly, if slowly paced, research and development effort was soon to receive high priority.[58]

Sputniks I and II, with their "Pearl Harbor" effect on public opinion, introduced into space affairs the issues of national pride and international prestige. The administration now moved quickly to restore confidence at home and prestige abroad. The Defense Department authorized the Army to launch a scientific satellite as a backup to the National Science Foundation-Navy Vanguard Project, and the president created the Advanced Research Projects Agency (ARPA), assigning it temporary responsibility for directing all U.S. space projects. James Killian, recently named Science Advisor to the President, also changed his mind. More funds were made available to the military space program, and in early 1958 the administration approved launching these satellites sooner with Thor IRBM boosters. Secretary of Defense Neil McElroy, who succeeded Charles Wilson in Sputnik's aftermath, ordered ARPA to launch space vehicles to "provide a closer look at the moon."[59]

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54. Wilson as quoted by Harr, "Eisenhower's Approach to National Security Decision Making," p. 96, and as quoted in "Memorandum of Discussion at the 322d Meeting of the National Security Council, Washington, May 10, 1957," in *Volume XI* [345], p. 752.

55. Allen W. Dulles, Director of Central Intelligence, to The Honorable Donald Quarles, Deputy Secretary of Defense, July 5, 1957, Eisenhower Library.

56. Quarles subsequently drew congressional fire for also restricting the flow of funds to the high-priority missile program. See "Quarles on the Spot," in *Washington Roundup, Aviation Week*, October 28, 1957, p. 25.

57. In his first news conference after the launch of Sputnik I on October 9, 1957, President Eisenhower let slip his true interest in the event, though it went unnoticed in the excitement of the day. "From what they say they have put one small ball in the air," the President declared, adding, "at this moment you [don't] have to fear the intelligence aspects of this." *Public Papers of the President of the United States: Dwight David Eisenhower, 1957* (Washington DC: U.S. Government Printing Office, 1958), p. 724.

58. Eisenhower's advisors had anticipated the launch of a Soviet satellite before the United States, and the Operations Coordinating Board, established within the structure of the National Security Council by Executive Order 10700, February 25, 1957, had prepared a contingency statement to be handled by the National Academy of Sciences. See Operations Coordinating Board, "Memorandum of Meeting: Working Group on Certain Aspects of NSC 5520 (Earth Satellite), Fourth Meeting held 3:30 P.M., June 17, 1957, Room 357 Executive Office Building," and attachment: "Contingency Statement; Proposed Statement by Dr. Detlev W. Bronk, President of the National Academy of Sciences, in the Event the U.S.S.R. Announces Plans for or the Actual Launching of an Earth Satellite," NASA Historical Reference Collection; Herbert F. York, *Race to Oblivion* (New York: Simon and Schuster, Clarion Book, 1970), pp. 106, 146.

59. Defense Secretary Wilson had announced plans to resign before the launch of Sputnik I. These actions and events are described in National Security Council (NSC) Action No. 1846, January 22, 1958, as cited in National Security Council, NSC 5814/1, "Preliminary U.S. Policy on Outer Space," August 18, 1958, p. 20; Mosely, *Dulles: A Biography of Eleanor, Allen, and John Foster Dulles*, p. 432; Prados, *The Soviet Estimate*, pp. 106-107; DOD News Release No. 288-58, March 27, 1958; see also ARPA Orders No. 1-58 and 2-58, March 27, 1958, all in NASA Historical Reference Collection. The new satellite project is described by Kistiakowsky in *A Scientist at the White House*, p. 378.

There was an undeniable public concern with Soviet leadership in outer space exploration. Eisenhower declared on April 2, 1958, that a unified national space agency had to be established.[60] Few disagreed, certainly not the U.S. scientists who had begun to seriously consider the future of research in space, the prospects for obtaining more federal funds for this activity, and the ways of organizing it within the government.[61] [II-16] During the subsequent dialogue and in legislative action, the nation's political leaders endorsed the president's choice of civilian control of expanded U.S. space activities. Except for national defense space operations, for which the Department of Defense remained responsible, the National Aeronautics and Space Act declared that all non-military aeronautical and space endeavors sponsored by the United States would be directed by a civilian agency guided by eight objectives. First among them was basic scientific research, defined as "the expansion of human knowledge of phenomena in the atmosphere and space...." Signed into law by President Eisenhower on July 29, the act wrote a broad and comprehensive mandate for the peaceful pursuit of new knowledge and accompanying technology in space.[62] [II-17]

The National Aeronautics and Space Administration (NASA), formed with the National Advisory Committee for Aeronautics (NACA) as its nucleus, began operating on October 1, 1958, with the ongoing scientific satellite and planetary exploration projects inherited from the National Science Foundation and ARPA. Air Force and other service leaders, limited exclusively to approved military space missions, still had to translate existing plans into functioning systems. Those military satellite projects already underway and projected at the end of 1958 formed the basic military space program.[63] It encompassed five functional areas and, with one exception, consisted of non-piloted military spaceflight projects (see Table 1).[64] In years to come, the Air Force would for the most part retain responsibility for technically managing and launching military spacecraft. Operational direction of the individual projects frequently was assigned elsewhere.[65]

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[60] Robert Vexler, ed., *Dwight D. Eisenhower, 1880-1969, Chronology, Documents, Bibliographical Aids* (Dobbs Ferry, NY: Oceana Publications, Inc., 1972), p. 42. NASA's enabling act was drafted by the NACA General Counsel Paul G. Dembling in January-February 1958. Endorsed by James Killian and other White House officials, and submitted to Congress by the President on April 2, the act passed essentially as first drawn—with the addition of a National Aeronautics and Space Council perhaps the most notable change. In recent years, however, some scholars have argued that congressional agitation forced the issue of a civil space agency on a reluctant president. See, for example, Derek W. Elliott, "Finding an Appropriate Commitment: Space Policy Development Under Eisenhower and Kennedy, 1954-1963," Ph.D. dissertation, The George Washington University, May 10, 1992.

[61] See Chapter Four of this volume for a discussion of the debate over organizing the space agency.

[62] National Aeronautics and Space Act of 1958, Sec. 102(a) and 102(c); Frank W. Anderson, Jr., *Orders of Magnitude: A History of NACA and NASA, 1915-1980* (Washington, DC: NASA SP-4401, 1981), p. 17; Maier, in Kistiakowsky, *A Scientist at the White House*, pp. xxxviii-xxxxix. An elucidation of the reasons for and objectives of using and exploring space are contained in a contemporary brochure issued by the President's Science Advisory Committee, "Introduction to Outer Space," March 26, 1958, NASA Historical Reference Collection.

[63] Various Air Force officials, it is true, attempting to gain responsibility for directing the nation's space program in 1958, did graft to this basic plan and present to Congress all sorts of exotic space proposals, including manned and unmanned orbital bombardment systems and even lunar military bases from which to attack countries on Earth. Besides flying in the face of stated administration commitments to explore and use outer space for peaceful and defensive purposes only, these proposals gained few adherents other than those who already viewed the Soviet sputniks with unalloyed hysteria.

[64] This program plan, it is also true, does not appear in this form in contemporary documents. The proposed manned rocket bomber (ROBO), later called Dyna-Soar (X-20), remained the sole exception to space robotics and in research and development until canceled in the early 1960s. Notwithstanding the variations that marked it afterward, the 1958 plan featured automated spacecraft and reflects the basic American military space program in effect today.

[65] Neil McElroy, Secretary of Defense, Memorandum to Chairman of the Joint Chiefs of Staff, "Responsibility for Space Systems," September 18, 1959, in Alice C. Cole, *et. al.*, eds., *The Department of Defense: Documents on Establishment and Organization* (Washington DC: Office of the Secretary of Defense, 1978), p. 325; also DOD Directive No. 5160.32, "Development of Space Systems," March 6, 1961, as reprinted in *Ibid.*

Table 1

Military Space Program Plan
(November 1958)

Functions	*Projects*
Navigation	Transit navigation satellite system; assigned to the Navy on May 9, 1960
Meteorology	Tiros television (RCA) satellite system assigned to NASA; military system proposed, but held to studies while negotiations for a single civil-military system were underway with NASA and the Department of Commerce (Weather Bureau)
Communication	Courier active (repeater) strategic and tactical communication satellite system; assigned to the Army on September 15, 1960
Missile Detection and Space Defense	Infrared radiometers that detect focused and Space Defense heat sources (Missile Detection and Alarm—MIDAS)
	Detection of nuclear detonations (Vela Hotel)
	Satellite inspector
	ROBO/Dyna-Soar (X-20)
	Radar tracking of Earth satellites (SPASUR/SPADATS)
	Optical tracking of satellites (from IGY Baker-Nunn system)
	Distant Early Warning (DEW) radar net and, by the early 1960s, the Ballistic Missile Early Warning System (BMEWS) radar net
Reconnaissance	Other automated satellites

Making Straight the Way

When NASA opened for business in October 1958, periodic U-2 flights over limited areas of the U.S.S.R. had been underway for two years. The Soviets protested vigorously, albeit privately, through diplomatic channels, and administration leaders knew that improved ground-to-air missiles would soon preclude all such missions.[66] Late in the year, President Eisenhower officially notified the Russians once again that the United States specifically sought to allay fears of surprise attack and create an inspection system to supervise arms-reduction agreements by means of aerial *and* space observation. He did so by

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[66] Eisenhower himself viewed these overflights in Soviet airspace as exceptionally provocative and a grave violation of national sovereignty; before personally approving each mission, he had to be convinced of the overriding need for it.

submitting a third, much more significant Open Skies proposal at an extraordinary "Surprise Attack Conference" sponsored by the United Nations in Geneva.[67]

Making his proposal the more remarkable, Eisenhower authorized his representatives, William C. Foster, later head of the Arms Control and Disarmament Agency, and Harvard chemist George Kistiakowsky, to include a "sanitized" version of the threat-and-warning portions of the surprise-attack indications matrix supplied by the National Indications Center. He thus furnished Soviet officials key indicators with which to assess the military status of states in the North Atlantic Treaty Organization—if they had not already devised similar warning indicators independently. The Soviets once again rejected Open Skies, though the U.S. position on the issue was made plain.[68] Even if the Soviets continued to reject the concept in international conference, might not the precepts of international law now be applied to achieve it?

One year earlier, Sputniks I and II had overflown international boundaries without provoking diplomatic protests. Four days after Sputnik I, in fact, Eisenhower and Deputy Secretary of Defense Donald Quarles discussed the issue. Quarles observed: "...the Russians have...done us a good turn, unintentionally, in establishing the concept of freedom of international space.... The President then looked ahead...and asked about a reconnaissance [satellite] vehicle."[69] The U.S. IGY Explorer and Vanguard satellites that followed the first sputniks into orbit in early 1958 likewise transited the world, and again not a single state objected to these overflights. The civil spacecraft would make straight the way for their military counterparts. Testifying before the U.S. House of Representatives in May 1958, Quarles underscored this point for a member of Congress skeptical that the United States should not object to Soviet reconnaissance satellites. "In a military sense," Quarles said, careful to speak only for the Department of Defense, "it seems to me that objects orbiting in outer space have an international character by the very nature of their position there, and it would be inappropriate for us to take the position that what you could see from there of our area would be improper for them to see.... I just think we cannot establish that kind of position that these [military satellites] are improper or objectionable or offensive. So I would have the view that we would not seek to object to such reconnaissance."[70] This tenuous "freedom of space" principle, the right of unrestricted overflight in outer space, the evidence indicates President Eisenhower purposely sought to exploit and codify when he signed the 1958 Space Act. That signature formally divided U.S. astronautics between civilian science and military applications directed to "peaceful"—that is, scientific—or defensive and nonaggressive purposes.

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[67] The second proposal Eisenhower submitted directly to Nikolai A. Bulganin, Chairman of the Soviet Council of Ministers, on March 2, 1956, eight months after the original proposal in Geneva. In it, Eisenhower agreed to accept on-site inspection teams if the Soviets would accept Open Skies. It, too, was rejected. See Ambrose, *Eisenhower: Volume II,* p. 311.

[68] Annex 5 and Annex 6 of "Report of the Conference of Experts for the Study of Possible Measures Which Might be Helpful in Preventing Surprise Attack and for the Preparation of a Report Thereon to Government," United Nations General Assembly, A/4078, S/4145, January 5, 1959; William C. Foster, "Official Report of the United States Delegation to the Conference of Experts for the Study of Possible Measures Which Might be Helpful in Preventing Surprise Attack and for the Preparation of a Report Thereon to Governments," Geneva, Switzerland, November 10-December 18, 1958, p. 10, Eisenhower Library.

[69] Quarles and Eisenhower remarks quoted in Walter A. McDougall, *The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, Inc., 1985), p. 134; an abridged version, less the reference to military satellites, appears in "Memorandum of a Conference, President's Office, White House, Washington, October 8, 1957, 8:30 a.m.," *Volume XI* [347], pp. 755-56. Walter McDougall and Stephen Ambrose, without access to classified documents, correctly perceived the intent of Eisenhower's satellite decision and the rationale behind it. McDougall, *The Heavens and the Earth,* chapter 5; Ambrose, *Eisenhower: Volume II,* pp. 428, 513-14. Quarles, architect of the nation's space policy, reiterated for administration leaders the importance of the principle "freedom of space" and its implications for military observation satellites at a meeting of the National Security Council on October 10, 1957, in *Volume XI* [348], p. 759.

[70] U.S. Congress, House, Select Committee on Astronautics and Space Exploration, *Astronautics and Space Exploration,* 85th Cong., 2d sess. (Washington, DC: U.S. Government Printing Office, 1958), p. 1109.

President Eisenhower amplified his space policy with National Security Council directives in June and August 1958 and January 1960. Anticipating the launch of military satellites, the first directive called for a "political framework which will place the uses of U.S. reconnaissance satellites in a political and psychological context most favorable to the United States." The second directive judged these spacecraft to be of "critical importance to U.S. national security," identified them with the peaceful uses of outer space, and set as an objective the "'opening up' of the Soviet Bloc through improved intelligence and programs of scientific cooperation." The third directive described the military support missions in space that fell within the rubric of peaceful uses, identified offensive space-weapon systems for study, and noted a positive political milestone in international law. The United Nations *Ad Hoc* Committee on the Peaceful Uses of Outer Space now accepted the "permissibility of the launching and flight of space vehicles...regardless of what territory they passed over during the course of their flight through outer space." But the UN Committee, the directive confided, at the same time stipulated that this principle pertained only to flights involved in the "peaceful uses of outer space."[71] [II-18, II-19, II-20, II-21]

Hewing to the policy of "freedom of space" and the peaceful space activities they defined for it, Eisenhower administration officials would in the months ahead permit only the study of offensive space weapons such as space-based antiballistic missile systems, satellite interceptors, and orbital bombers that could threaten the precedent of free passage.[72] This space policy, endorsed by President Eisenhower's successor, John F. Kennedy, secured two objectives simultaneously and permitted the launch and operation of military reconnaissance spacecraft. First, it reinforced the "sputnik precedent" as an accepted principle among states, officially recognizing free access to and unimpeded passage through outer space for peaceful purposes. [II-22] Second, by limiting military spacefaring to defense-support functions, it avoided a direct confrontation with the Soviet Union over observation of the Earth from space and ensured at least an opportunity to achieve Open Skies at altitudes above the territorial airspace of nation states. Thus, without formal convention, the United States could fashion unilaterally an "inspection system" to forewarn of surprise attack and supervise and verify future arms-reduction and nuclear-test-ban treaties.

But if the IGY scientific satellites had set an international precedent, and if publicly the United States was committed to a visible space program under civilian management, at the end of 1958 the actual launch and operation of military spacecraft had still to test President Eisenhower's policy—and Soviet reaction.

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[71] NSC 5814, "U.S. Policy on Outer Space," June 20, 1958, paragraph 54; NSC 5814/1, "Preliminary U.S. Policy on Outer Space," August 18, 1958, paragraphs 21, 30, and 47; NSC 5918, "U.S. Policy on Outer Space," December 17, 1959, paragraphs 18, 19, and 23.

[72] The administration's rationale in opposing anything more than the study of space-based weapons is explained in Kistiakowsky, *A Scientist at the White House*, pp. 229-30, 239-40, and 245-46. A few days after the launch of Sputnik I, having just discussed this rationale with Eisenhower, Deputy Secretary of Defense Donald Quarles surprised and chagrined Air Force leaders who briefed him on the military satellite program and the potential of satellites for offensive applications: "Mr Quarles took very strong and specific exception to the inclusion in the presentation of any thoughts on the use of a satellite as a (nuclear) weapons carrier and stated that the Air Force was out of line in advancing this as a possible application of the satellite. He verbally directed that any such applications not be considered further in Air Force planning. Although both General [Curtis] LeMay and General [Donald] Putt voiced objection to this...on the grounds that we had no assurance that the U.S.S.R. would not explore this potential of satellites and could be expected to do so, Mr. Quarles remained adamant." Colonel F. C. E. Oder, USAF, Director, WS 117L, Memorandum for the Record, "Briefing of Deputy Secretary of Defense Mr. Quarles on WS 117L on 16 October 1957," October 25, 1957, Eisenhower Library.

Amplifying administration policy a year later, on October 20, 1958, ARPA Director Roy Johnson ordered the Air Force to cease using the Weapon System (WS) designation in the military satellite program "to minimize the aggressive international implications of overflight.... It is desired to emphasize the defensive, surprise-prevention aspects of the system. This change...should reduce the effectiveness of possible diplomatic protest against peacetime employment." Roy Johnson, Director, ARPA, to Maj. General Bernard Schriever, Cmdr., Air Force Ballistic Missile Division, Air Research and Development Command, n.s., October 20, 1958, Eisenhower Library. Despite these and subsequent messages that canceled offensive space-based, weapon-research programs, Air Force military leaders at that time seemed unable to grasp—or unwilling to accept—the meaning of President Eisenhower's "peaceful uses of outer space," or the rationale behind it.

Document II-1

Document title: Louis N. Ridenour, "Pilot Lights of the Apocalypse: A Playlet in One Act," *Fortune*, Vol. 33, January 1946.

This brief "playlet" offered the first public account of an intercontinental nuclear war directed from underground command centers and conducted using space-based weapons. Written by Louis Ridenour, a physicist who helped develop radar technology at MIT's Radiation Laboratory during World War II, it appeared in print just five months after the atomic bombing of Hiroshima and Nagasaki.

Concern over a nuclear surprise attack led President Dwight D. Eisenhower to propose "Open Skies" and establish a national policy (with the intent to promote an international precedent) of "freedom of space." That policy and subsequent precedent permitted the United States to employ without contest early warning satellites and other Earth-orbiting observation systems.

Pilot Lights of the Apocalypse

A Playlet in One Act

by Louis N. Ridenour

Louis N. Ridenour wrote "Military Security and the Atomic Bomb" in the November issue of Fortune, *attacking the notion that the U.S. could achieve "security by concealment" of its scientific knowledge of atomic power. Since then the principle underlying his view seems to have been incorporated in Anglo-American policy. Dr. Ridenour, a nuclear physicist and a professor of physics at the University of Pennsylvania, went to M.I.T.'s Radiation Laboratory four years ago and helped develop radar weapons there. He believes that while "security by achievement" may determine any victory, the difference between victor and vanquished in a war fought with atomic power would be merely a few percentiles of obliteration. And he fears that such a war will be inescapable if there is an atomic armaments race, since the slightest error, such as often occurs when men under great tension become trigger-happy, would touch off stupendous destruction.*

Dr. Ridenour has not tried to write a fantasy; he has tried to put into the form of a grim playlet the sober conclusions to which he feels driven by knowledge of physics, weapons, and human behavior. His moral: we should do all that decently can be done to avoid an atomic-armaments race.

What that "all" may be, he does not, as a natural scientist, attempt to define. Further definition is the job of social scientists, statesmen, philosophers, and citizens.

The curtain rises to disclose the operations room of the Western Defense Command, somewhere in the San Francisco area and a hundred feet underground. Two sergeants, RIGHT, are tending a row of teletype machines that connect the room with the world's principal cities. Two others, REAR, sit before a sort of telephone switchboard with key switches, lights, and labels representing the world's major cities. Behind them stands a captain. At a large desk, CENTER, sit a brigadier general and two colonels, all reading teletype messages. The wall, LEFT, has a sturdy barred door, a world map, and a framed motto: "Remember Pearl Harbor."

TIME: Some years after all the industrialized nations have mastered the production and use of atomic power.

BRIGADIER (laying down the message he has been reading): Nothing much tonight, I'd say. We'd better get tidied up a little. Captain Briggs!

CAPTAIN (facing about and standing at attention): Yes, sir.

BRIGADIER: Ready for company?

CAPTAIN: Yes, sir. I think so, sir.

BRIGADIER: See that the men look busy—on their toes and busy.

CAPTAIN: Yes, sir. (A bell rings.) Schwartz, you get the door. (One of the sergeants crosses to the door and opens it. All stand rigidly at attention. A little confused, the sergeant goes through the formality of examining passes. He then admits a group of four: a four-star general, a major, and two civilians.)

GENERAL: Carry on. (The men relax. The General leads the two civilians over to the Brigadier and the Colonels. The Major takes up his station by the door. Nobody pays any attention to him.) Mr. President, this is General Anderson, Watch Officer in charge of the Operations Room.

THE PRESIDENT: How do you do?

BRIGADIER: How do you do, Sir? (They shake hands.)

GENERAL: Colonel Sparks and Colonel Peabody, Deputy Watch Officers on duty.

THE PRESIDENT: Glad to meet you both. (They shake hands.)

GENERAL: Dr. Thompson—General Anderson, Colonel Sparks, and Colonel Peabody. (All nod and smile.) Now, Mr. President, this is the nerve center of our counterattack organization for the western area. The teletype machines you see over there (pointing) are on radio circuits that connect us with our people in all the principal cities of the world, and with the other continental defense commands. The stations, and their statuses, are marked on the map. (He gestures toward the map.) We've just come from the defense center, where the radar plots are kept and the guns and the fighters controlled. That's defense. But this is counterattack. Along that wall (waving toward the rear) is our control board. If you'll step over here, sir, I'll show you how it works.

THE PRESIDENT (moving with the General toward the telephone switchboard against the back wall): Defense and counterattack, eh? Why keep them separate?

GENERAL: Well, the defense has to move quickly, or it's no good at all. They don't have time to think. But counterattack—well, counterattack has to move quickly, too. But we want them to have time to decide what they need to do. You can't tell just from the direction of an attack who launched it. An attack might be staged entirely by mines planted inside our borders, so there wouldn't be any direction connected with it. And then again, we have pretty good information that some other countries besides us have got bombs up above the stratosphere, 800 miles above the earth, going round us in orbits like little moons. We put up 2,000 and we can see about 5,400 on our radar. Any time, somebody can call down that odd 3,400 by radio and send them wherever they want. There's no telling from trajectory which nation controls those bombs. What this all means is that the data these fellows here have to go on is mainly political. Radar doesn't do them any good. What they need is intelligence, and that's what comes in all the time, as complete and up-to-date as we can get it on the teletypes. In the defense center, you saw scientists and technicians. The officers here are political scientists.

THE PRESIDENT: That's very interesting. Maybe you'll give me a job here if I ever need one. I'm a political scientist.

GENERAL (laughing just enough): Yes, sir!

THE PRESIDENT: General, you haven't told me what all these gadgets are for. (He waves toward the switchboard.)

GENERAL: No, sir, I haven't. This is our counterattack control board. You see that every station is marked with the name of a city. And every station has three pilot lights: red, yellow, and green.

THE PRESIDENT: All the green ones are on.

GENERAL: That's right, sir. We have unattended radio transmitters, each with three spares, in stations in every city covered on this board. If one of the transmitters goes on the blink, a spare is automatically switched on. But if all four transmitters in any station are destroyed, well, we lose the signal from that station. When that happens the green light goes out and the yellow light comes on.

THE PRESIDENT: How about the red light?

GENERAL: That comes on instead of the yellow when all our stations in the whole city go off the air. Yellow means partial destruction—red means substantially complete destruction.

THE PRESIDENT: And green means peace.

GENERAL: Yes, sir. But this isn't just a monitoring board. You see this key here?

THE PRESIDENT: Yes.

GENERAL: That sets off our mines. We have them planted in a great many cities, and the radio control circuit can be unlocked from here.

THE PRESIDENT: Is the whole world mined now?

GENERAL: Well, no. We haven't bothered much with Asia. And some countries are so hard to get into that coverage is spotty. Our schedule calls for completion of mine installations in two more years. But we have another card to play. You remember I told you about the satellite bombs—the ones that are circling around, 800 miles up?

THE PRESIDENT: Yes.

GENERAL: Well, this other key here will bring them down on the city shown on the marker—we are looking at Calcutta—one of those satellite bombs every time it is pressed.

THE PRESIDENT: Is one of those bombs earmarked for each particular city?

GENERAL: No, sir. The bomb that happens to be in the most favorable location at the time this key is pressed is the one brought down. It might be any one of the whole 2,000.

THE PRESIDENT: This is all damned clever.

GENERAL: We have Dr. Thompson to thank for most of it. His people worked out all the technical stuff. All the Army has to do is man the installations and watch the intelligence as it comes along.

DR. THOMPSON: Good of you to say that, General. But seriously, Mr. President, as people pointed out soon after the first atomic bomb was dropped, there isn't any other nation with the industrial know-how to do a job like this.

THE PRESIDENT: It's very impressive, I must say. Are the other Defense Commands equipped the same way?

GENERAL: Yes, sir. As a matter of fact, to guard against accidents, each Defense Command has two complete operations rooms like this, either one of which can take full control if the other is destroyed.

THE PRESIDENT: We've kept ahead in the armaments race. Who'd dare attack us when we're set up like this?

DR. THOMPSON: Surely nobody would. I don't think you need to expect any trouble.

THE PRESIDENT: Well, this has all been very interesting. (To the Brigadier) General, have you had any exciting times here you can tell me about?

BRIGADIER: Yes, sir. Every time a meteorite comes down—a shooting star, you know—our radar boys track it, shoot it down, and send us in an alert. We have a few bad moments until we get the spectrographic report. If it's iron and nickel—and it always has been so far—we know God sent it, and relax. Someday it'll be uranium, and then we'll have to push a button. Or plutonium.

THE PRESIDENT: How many shooting stars have you shot?

COLONEL SPARKS (laughing politely): We get an average of twelve a month. In August it's the worst, of course. The Perseids, you know.

THE PRESIDENT (puzzled): Iran. . . ?

BRIGADIER (hastily): No, sir. The Perseid meteors. Named after Perseus. Astronomers are a classical bunch.

THE PRESIDENT (recovering): Oh, sure. (Turning to the Colonels) Gentlemen, how do you like this job?

COLONEL SPARKS: We have a feeling of grave responsibility.

THE PRESIDENT: The fate of the nation is in your hands. But always remember that our nation is the most precious.

BOTH COLONELS (awed): Yes, sir.

GENERAL: Well, Mr. President. We've fallen a little behind our schedule. They'll be waiting for us at the mess.

THE PRESIDENT: All right, General, let's get along. General Anderson, Colonel Sparks, Colonel Peabody, I've enjoyed very much seeing your installation. Keep on your toes. We're all depending on you.

GENERAL AND COLONELS (together): Yes, sir.

(Schwartz goes over, opens the door, and stands stiffly at attention as the visitors file out amid a general chorus of "Goodbye" and "Goodbye, sir." Schwartz closes the door. The Brigadier and Colonels sit at their desks.)

BRIGADIER: Well, that's that. The Old Man gave him a good story; I couldn't have done better myself.

COLONEL SPARKS (still in the clouds): He is depending on us.

BRIGADIER: Don't take it too hard. All we're supposed to do is make the other guy sorry. We can't save any lives or rebuild any cities. Never forget what those buttons do.

COLONEL SPARKS: Just the same, sir, I'm glad I was born an American. We've got the know-how. I'm glad I'm on the side that's ahead in the race.

COLONEL PEABODY (disgusted): Sparks, you talk like a damn high-school kid. For this job, you're supposed to have some good sense and detachment.

(Just then, there is a dull rumble. The floor and the walls of the room shake, and a couple of sizable chunks of concrete fall out of the ceiling. The lights go out, except for the green ones on the control board. Emergency lights, dimmer than the regular ones, come on at once. All the men are on their feet.)

BRIGADIER: Good God! What was that? (Recollecting himself) Peabody, get on the phone to headquarters. Sparks, get out the red-line messages for the last twenty-four hours. Captain, anything from the defense center?

CAPTAIN: My line to them seems to be out, sir.

BRIGADIER: What have you got for status? Anybody showing yellow or red?

CAPTAIN: San Francisco is red, sir.

COLONEL SPARKS (riffling wildly through teletype messages): Oh, Jesus. This must be it. San Francisco! (Screaming) San Francisco gone!

BRIGADIER: Shut up, Sparks. Take it easy. (To Peabody) Can't you get headquarters?

COLONEL PEABODY: My line is dead. I can't get reserve operations, either. Maybe this is the real thing.

COLONEL SPARKS (still half hysterical): We better do something. Remember what it says in the book: counterattack must take action before the enemy's destruction of our centers is complete.

BRIGADIER: First we need an enemy. Who's got the highest negative rating in the latest State Department digest?

COLONEL PEABODY (who has quietly taken the messages from in front of Sparks): Denmark, sir. But it's well below the danger point. All we've got is this: (reading) COPENHAGEN 1635 HOURS 22 JANUARY. WIDESPREAD DISAPPROVAL OF WILLIAMS FOUNTAIN, STATUARY GROUP PRESENTED THE KING DENMARK BY THE U.S., BEING SHOWN BY PEOPLE COPENHAGEN. FOUNTAIN HAS BEEN PELTED VEGETABLES BY HOODLUM GROUPS THREE OCCASIONS. FORMAL PROTEST STATING STATUE INSULTS KING RECEIVED FROM ROYAL ACADEMY ART IN FOLLOWING TERMS QUOTE...and so on. Nothing there, I'd say.

COLONEL SPARKS: Nothing there! San Francisco's in ruins, you damn fool, and we're sitting here like three warts on a pickle. All that over a lousy set of statues. I say let'em have it.

BRIGADIER (to Peabody): Is that the hottest you've got?

COLONEL PEABODY: Yes, sir. I don't think it could have been Denmark. Though that sculptor, Williams, does live in San Francisco.

BRIGADIER: We'd better wait and be sure. Captain, how are your lines now?

COLONEL SPARKS (with rising hysteria): What have we got this stuff for if we don't use it? My God, didn't you hear what the President said? He's depending on us; they're all depending on us. If you haven't got the guts, I have. (Before he can be stopped, he rushes to the control board and shoves a sergeant to the floor. Peabody is after Sparks in a flash. He pulls him around and knocks him to the floor. Sparks's head hits hard, and he lies still.

COLONEL PEABODY: General, he did it! Copenhagen shows red!

SERGEANT (at a teletype): Sir, here's a message from the defense center. They've got their line working again. (He tears it off and brings it to the Brigadier.)

CAPTAIN: Stockholm's gone red, sir.

COLONEL PEABODY: Sure. The Danes thought it was the Swedes. That export-duties row.

BRIGADIER: And the Swedes have got two hot arguments on their hands. They'll take the British, too, just to be sure. The British soak the Russians, and then we're next. (He reads the message he has been holding, and drops into a chair.) My God! Peabody, that was an earthquake. Epicenter right smack in San Francisco.

CAPTAIN: London's gone red, sir. And Edinburgh, and Manchester, and Nottingham, and—

COLONEL PEABODY: Dark ages, here I come. It's a pity the Security Council didn't have time to consider all this.

BRIGADIER: Peabody, you're beginning to sound a little like Sparks. Come to think of it, there was nothing wrong with him but too much patriotism and too little sense. Captain, we probably can't pull this out of the fire, but we've got to try. Send a message on all circuits. (The Captain sits down at a teletype keyboard.)

CAPTAIN: Ready, sir.

BRIGADIER: To all stations: URGE IMMEDIATE WORLDWIDE BROADCAST THIS MESSAGE: DESTRUCTION COPENHAGEN 1910 HOURS THIS DATE INITIATED BY THIS STATION THROUGH GRIEVOUS ERROR. ATTACKS MADE SINCE BASED ON IDEA DESTRUCTION COPENHAGEN WAS ACT OF WAR, WHICH IT WAS NOT REPEAT NOT. URGE ATTACKS BE STOPPED UNTIL SITUATION CAN BE CLARIFIED. THERE IS NO REPEAT NO WAR. END.

COLONEL PEABODY (who has been watching board): The hell there isn't. New York's gone red, and Chicago, and. . . (The room rocks, the lights go out. With a dull, powerful rumble, the roof caves in.)

CURTAIN

Document II-2

Document title: Douglas Aircraft Company, Inc., "Preliminary Design of an Experimental World-Circling Spaceship," Report No. SM-11827, May 2, 1946, pp. i-viii, 1-16, 211-12.

Source: Archives, The Rand Corporation, Santa Monica, California.

The newly formed Rand group, a unit of Douglas Aircraft, was directed by General Curtis LeMay to investigate the possible uses of satellites for the Air Force. LeMay took this action after he learned that the Navy was conducting a similar study. The resulting report, released in May 1946, was the first study completed by Rand and the first comprehensive analysis of the military uses of satellites. It suggested that satellites had broad uses in meteorology, reconnaissance, and communications. But while extensive in scope and providing much new information on the value of satellites, including the possibility of a vehicle that could carry humans, the report was virtually ignored by the Air Force, which was unconvinced as to the utility of satellites and unwilling to support a report that questioned the role of the manned bomber. These excerpts from the report, which contained 236 pages plus several lengthy appendices, give a sense of the broader thinking that guided the engineering analyses that comprised the bulk of the document.

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Summary

This report presents an engineering analysis of the possibilities of designing a man-made satellite. The questions of power plants, structural weights, multiple stages, optimum design values; trajectories, stability, and landing are considered in detail. The results are used to furnish designs for two proposed vehicles. The first is a four stage rocket using alcohol and liquid oxygen as propellants. The second is a two stage rocket using liquid hydrogen and liquid oxygen as propellants. The latter rocket offers better specific consumption rates, but this is found to be partially offset by the greater structural weight necessitated by the use of hydrogen. It is concluded that modern technology has advanced to a point where it now appears feasible to undertake the design of a satellite vehicle.

[ii]

Abstract

In this report, we have undertaken a conservative and realistic engineering appraisal of the possibilities of building a spaceship which will circle the earth as a satellite. The work has been based on our present state of technological advancement and has not included such possible future developments as atomic energy.

If a vehicle can be accelerated to a speed of about 17,000 m.p.h. and aimed properly, it will revolve on a great circle path above the earth's atmosphere as a new satellite. The centrifugal force will just balance the pull of gravity. Such a vehicle will make a complete circuit of the earth in approximately 1-½ hours. Of all the possible orbits, most of them will not pass over the same ground stations on successive circuits because the earth will turn about $^1/_{16}$ of a turn under the orbit during each circuit. The equator is the only such repeating path and consequently is recommended for early attempts at establishing satellites so that a single set of telemetering stations may be used.

Such a vehicle will undoubtedly prove to be of great military value. However, the present study was centered around a vehicle to be used in obtaining much desired scientific information on cosmic rays, gravitation, geophysics, terrestrial magnetism, astronomy, meteorology, and properties of the upper atmosphere. For this purpose, a payload of 500 lbs. and 20 cu ft. was selected as a reasonable estimate of the requirements for scientific apparatus capable of obtaining results sufficiently far-reaching to make the undertaking worthwhile. It was found necessary to establish the orbit at an altitude of about 300 miles to insure sufficiently [iii] low drag so that the vehicle could travel for 10 days or more, without power, before losing satellite speed.

The only type of power plant capable of accelerating a vehicle to a speed of 17,000 m.p.h. on the outer limits of the atmosphere is the rocket. The two most important performance characteristics of a rocket vehicle are the exhaust velocity of the rocket and the ratio of the weight of propellants to the gross weight. Very careful studies were made to establish engineering estimates of the values that can be obtained for these two characteristics.

The study of rocket performance indicated that while liquid hydrogen ranks highest among fuels having large exhaust velocities, its low density, low temperature and wide explosive range cause great trouble in engineering design. On the other hand, alcohol, though having a lower exhaust velocity, has the benefit of extensive development in the German V-2. Consequently it was decided to conduct parallel preliminary design studies of vehicles using liquid hydrogen-liquid oxygen and alcohol-liquid oxygen as propellants.

It has been frequently assumed in the past that structural weight ratios become increasingly favorable as rockets increase in size, and fixed weight items such as radio equipment become insignificant weight items. However, the study of weight ratios indicated that for large sizes the weight of tanks and similar items actually become less favorable. Consequently, there is an optimum middle range of sizes. Improvements in weight ratios over that of the German V-2 are possible only by the slow process of technological development, not by the brute force methods of increase in size. This study showed that an alcohol-oxygen vehicle [iv] could be built whose entire structural weight (including motors, controls, etc.) was about 16% of the gross weight. On the other hand, the difficulties with liquid hydrogen, such as increased tank size, necessitated an entire structural weight of about 25% of the gross weight. These studies also indicated that a maximum acceleration of about 6.5 times that of gravity gave the best overall performance for the vehicles considered. If the acceleration is greater, the increased structural design loads increase the structural weight. If the acceleration is less, rocket thrust is inefficiently used to support the weight of the vehicle without producing the desired acceleration.

Using the above results, it was found that neither hydrogen-oxygen nor alcohol-oxygen is capable of accelerating a single unassisted vehicle to orbital speeds. By the use of a multi-stage rocket, these velocities can be attained by vehicles feasible within the limits of our present knowledge. To illustrate the concept of a multi-stage rocket, first consider a vehicle composed of two parts. The primary vehicle, complete with its rocket motor, tanks, propellants and controls is carried along as the "payload" of a similar vehicle of much greater size. The rocket of the large vehicle is used to accelerate the combination to as great a speed as possible, after which, the large vehicle is discarded and the small vehicle accelerates under its own power, adding its velocity increase to that of the large vehicle. By this means we have obtained an effective decrease in the amount of structural weight that must be accelerated to high speeds. This same idea can be used in designing vehicles with a greater number of stages. A careful analysis of the advantages of staging showed that for a given set of performance requirements, [v] an optimum number of stages exists. If the stages are too few in number, the required velocities can be attained only by the undesirable process of exchanging payload for fuel. If they are too many, the multiplication of tanks, motors, etc. eliminates any possible gain in the effective weight ratio. For the alcohol-oxygen rocket it was found that four stages were best. For the hydrogen-oxygen rocket, preliminary analysis indicated that the best choice for the number of stages was two, but refinements showed the optimum number of stages was three. Unfortunately, insufficient time was available to change the design, so the work on the hydrogen-oxygen was completed using two stages. The characteristics of the vehicles studies are tabulated below....

Vehicle Powered by Alcohol-Oxygen Rockets

Stage	1	2	3	4
Gross Wt. (lbs.)	233,669	53,689	11,829	2,868
Weight less fuel (lbs.)	93,669	21,489	4,729	1,148
Payload (lbs.)	53,689	11,829	2,868	500
Max. Diameter (in.)	157	138	105	90

Vehicle Powered by Hydrogen-Oxygen Rockets

Stage	1	2
Gross Wt. (lbs.)	291,564	15,364
Weight less fuel (lbs.)	84,564	4,464
Payload (lbs.)	15,364	500
Max. Diameter (in.)	248	167

[vi] (had three stages been used for the hydrogen-oxygen rockets, the overall gross weight of this vehicle could have been reduced to about 84,000 lbs. indicating this combination should be given serious consideration in any future study).

In arriving at the above design figures, a detailed study was made of the effects of exhaust velocity, structural weight, gravity, drag, acceleration, flight path inclination, and relative size of stages on the performance of the vehicles so that an optimum design could be achieved or reasonable compromises made.

It was found that the vehicle could best be guided during its accelerated flight by mounting control surfaces in the rocket jets and rotating the entire vehicle so that lateral components of the jet thrust could be used to produce the desired control forces. It is planned to fire the rocket vertically upward for several miles and then gradually curve the flight path over in the direction in which it is desired that the vehicle shall travel. In order to establish the vehicle on an orbit at an altitude of about 300 miles without using excessive amounts of control it was found desirable to allow the vehicle to coast without thrust on an extended elliptic arc just preceding the firing of the rocket of the last stage. As the vehicle approaches the summit of this arc, which is at the final altitude, the rocket of the last stage is fired and the vehicle is accelerated so that it becomes a freely revolving satellite.

It was shown that excessive amounts of rocket propellants are required to make corrections if the orbit is incorrectly established in direction or in velocity. Therefore, considerable attention was devoted to the stability and control problem during the acceleration to orbital [vii] speeds. It was concluded that the orbit could be established with sufficient precision so that the vehicle would not inadvertently re-enter the atmosphere because of an eccentric orbit.

Once the vehicle has been established on its orbit, the questions arise as to what are the possibilities of damage by meteorites, what temperatures will it experience, and can its orientation in space be controlled? Although the probability of being hit by very small meteorites is great, it was found that by using reasonable thickness plating, adequate protection could be obtained against all meteorites up to a size where the frequency of occurrence was very small. The temperatures of the satellite vehicle will range from about 40°F when it is on the side of the earth facing the sun to about -20°F when it is in the earth's shadow. Either small flywheels or small jets of compressed gas appear to offer feasible methods of controlling the vehicle's orientation after the cessation of rocket thrust.

An investigation was made of the possibility of safely landing the vehicle without allowing it to enter the atmosphere at such great speeds that it would be destroyed by the heat of air resistance. It was found that by the use of wings on the small final vehicle, the rate of descent could be controlled so that the heat would be dissipated by radiation at temperatures the structure could safely withstand. These same wings could be used to land the vehicle on the surface of the earth.

An interesting outcome of the study is that the maximum acceleration and temperatures can be kept within limits which can be safely withstood by a human being. Since the vehicle is not likely to be damaged by meteorites and can be safely brought back to earth, there is good reason [viii] to hope that future satellite vehicles will be built to carry human beings.

It has been estimated that to design, construct and launch a satellite vehicle will cost about $150,000,000. Such an undertaking could be accomplished in approximately 5 years time. The launching would probably be made from one of the Pacific islands near the equator. A series of telemetering stations would be established around the equator to obtain the data from the scientific apparatus contained in the vehicle. The first vehicles will probably be allowed to burn up on plunging back into the atmosphere. Later vehicles will be designed so that they can be brought back to earth. Such vehicles can be used either as long range missiles or for carrying human beings....

[1] 1. **Introduction**

Technology and experience have now reached the point where it is possible to design and construct craft which can penetrate the atmosphere and achieve sufficient velocity to become satellites of the earth. This statement is documented in this report, which is a design study for a satellite vehicle judiciously based on German experience with V-2, and which relies for its success only on sound engineering development which can logically be expected as a consequence of intensive application to this effort. The craft which would result from such an undertaking would almost certainly do the job of becoming a satellite, but it would clearly be bulky, expensive, and inefficient in terms of the spaceship we shall be able to design after twenty years of intensive work in this field. In making the decision as to whether or not to undertake construction of such a craft now, it is not inappropriate to view our present situation as similar to that in airplanes prior to the flight of the Wright brothers. We can see no more clearly all the utility and implications of spaceships than the Wright brothers could see fleets of B-29's bombing Japan and air transports circling the globe.

Though the crystal ball is cloudy, two things seem clear:

1. A satellite vehicle with appropriate instrumentation can be expected to be one of the most potent scientific tools of the Twentieth Century.

[2] 2. The achievement of a satellite craft by the United States would inflame the imagination of mankind, and would probably produce repercussions in the world comparable to the explosion of the atomic bomb.

Chapter 2 of this report attempts to indicate briefly some of the concrete results to be derived from a spaceship which circles the world on a stable orbit.

As the first major activity under contract W33-038AC-14105, we have been asked by the Air Forces to explore the possibilities of making a satellite vehicle, and to present a program which would aid in the development of such a vehicle. Our approach to this task is along two related lines:

1. To undertake a design study which will evaluate the possibility of making a satellite vehicle using known methods of engineering and propulsion.

2. To explore the fields of science in an attempt to discover and to stimulate research and development along lines which will ultimately be of benefit in the design of such a satellite vehicle and which will improve its efficiency or decrease its complexity and cost.

This report concerns itself solely with the first line of approach. It is a practical study based on techniques that we now know. The implications of atomic energy are not considered here. This and other possibilities in the fields of science may be the subject of future [3] reports, which will cover the second line of approach.

In the preliminary design study analytical methods have been developed which may be used as a basis for future studies in this new field of astronautical engineering. Among these are the following:

1. Analysis of single- and multi-stage rocket performance and methods for selecting the optimum number of stages for any given application.

2. Dimensional analysis of varying size and gross weight of rockets, deriving laws which are useful in design scaling. These laws are also of assistance in appraisal of the effect of shape and proportions on the design of multi-stage rockets.

3. The effect of acceleration and inclination of the trajectory on structural weight and performance of a satellite rocket.

4. Methods of determining the optimum trajectory for satellite rockets.

5. Variation of rocket performance with altitude and its effect on the proportioning of stages.

6. Preliminary study of effect of atmospheric drag on the rocket and how it affects the choice of stages, acceleration, and trajectory.

7. Analysis of dynamic stability and control throughout the entire trajectory.

[4] 8. Method of safely landing a satellite vehicle.

It cannot be emphasized too strongly that the primary contributions of this report are in methods, and not in the specific figures in this design study. *One point in particular should be highlighted: - the design gross weight, which is of the greatest importance in estimating cost or in comparing any two proposals in this field is the least definitely ascertained single feature in the whole process.* This fact is fundamental in the design of a satellite or spaceship, since the slightest variation in some of the minor details of construction or in propulsive efficiency of the fuel may result in a large change in gross weight. The figures in this report represent a reasonable compromise between the extremes which are possible with the data now in hand. The most important thing is that a satellite vehicle can be made at all in the present state of the art. Even our more conservative engineers agree that it is definitely possible to undertake design and construction now of a vehicle which would become a satellite of the earth.

Another important result of this design study is the conclusion on liquid hydrogen and oxygen as fuel versus liquid oxygen and alcohol (the Germans' fuel). The relative merits of these fuels have occasioned spirited controversy ever since liquid fuel rockets have been under development. In the past, the fact which has clinched the arguments has been the difficulty of handling, storing, and using liquid hydrogen. The present design study has approached this subject from another viewpoint. On the assumption that all these nasty problems can be solved, a design analysis has [5] been made for the structure and performance of rockets using both types of fuels. Because of the low density of liquid hydrogen, the greater tankage weight and volume tends to offset the increase in specific impulse. Early in the design study it was necessary to make a choice of the number of stages for both proposed vehicles. Based on the design information available, a decision was made to use four stages for the alcohol-oxygen rocket and two stages for the hydrogen-oxygen rocket. Of these two designs, the alcohol-oxygen rocket proved to be somewhat smaller in weight and size. However, the problem was later re-examined when more reliable data were available. It was found that, while the choice of four stages for alcohol-oxygen had been wise, the hydrogen-oxygen rocket could have been substantially improved by using three stages. The improvement was sufficient to indicate that the three stage hydrogen-oxygen rocket would have been definitely superior to the four stage alcohol-oxygen rocket. Unfortunately, the work had progressed so far that it was impossible to alter the number of stages for the hydrogen-oxygen rocket.

One of the most important conclusions of this design study is that in order to achieve the required performance it is necessary to have multi-state rockets for either type of fuel. The general characteristics of both types are shown in the following table:

4 Stage Alcohol-Oxygen Rocket

Payload 500#

Stage	1	2	3	4
Gross weight (lbs.)	233,669	53,689	11,829	2,868
Fuel weight (lbs.)	140,000	32,200	7,100	1,720

[6] 2 Stage Hydrogen-Oxygen Rocket

Payload 500#

Stage	1	2
Gross weight (lbs.)	291,564	15,364
Total Fuel wt. (lbs.)	217,900	10,000

The design represents a series of compromises. The payload is chosen to be as small as is consistent with carrying enough experimental equipment to achieve significant results. This is done for the purpose of keeping the gross weight within reasonable limits, since the gross weight increases roughly in proportion to the payload above a certain minimum value. The design altitude was originally chosen as 100 miles, since previous calculations indicated that the atmospheric drag there was not great enough to disturb the orbit of the satellite for a few revolutions, and since for communications purposes it was desirable to keep the satellite below the ionosphere. The more refined drag studies made in the present design study show that these early estimates were in serious error, and indicate that the satellite will have to be established at altitudes of 300 to 400 miles to ensure the completion of multiple revolutions around the earth.

It is interesting that the design analysis shows that the optimum accelerations are well within the limits which the human body can stand. Further, it appears possible to achieve a safe landing with the type of vehicle which is required. Future developments may bring an increase in payload and decrease in gross weight, sufficient to produce a large manned spaceship able to accomplish important things in a scientific [7] and military way.

We turn now from the design study phase to the basic research approach of the scientists. Our consultants have all made suggestions which have been taken into consideration in the preparation of this report. In the future it is our expectation that the services of these scientists will be of the greatest benefit in planning and initiating broad research programs to explore new fundamental approaches to the problem of space travel.

The real white hope for the future of spaceships is, of course, atomic energy. If this intense source of energy can be harnessed for rocket propulsion, then spaceships of moderate size and high performance may become a reality, and conceivably could even serve efficiently as intercontinental transports in the remote future. We are fortunate in having the consulting services of Drs. Alvarez, McMillan, and Ridenour, well known in scientific circles. Alvarez and McMillan were two of the key men at the Los Alamos Laboratory of the Manhattan Project. With the benefit of their advice, we hope to achieve a degree of competence in the fields of application of nuclear energy to propulsion.

Alvarez and Ridenour, who are also radar experts, have made basic analyses of the radio and radar problems associated with a satellite. These are of service in planning the new equipment which seems to be necessary to make the satellite a useful tool.

Kistiakowsky, a specialist in physical chemistry, has made valuable suggestions for the development of new rocket propellants.

[8] Schiff has contributed to our knowledge of the optimum trajectories to be used in launching the vehicle.

More important than the ideas and suggestions received to date is the fact that these consultants, who are among the leaders in U.S. science, have begun to think and work on these problems. It is our earnest hope that under the terms of this new study and research contract with the Army Air Forces we may be able to enlist the active cooperation of an important fraction of the scientific resources of the country to solve problems in the wholly new fields which man's imagination has opened. Of these, space travel is one of the most important and challenging.

[9] 2. The Significance of a Satellite Vehicle

Attempting in early 1946 to estimate the values to be derived from a development program aimed at the establishment of a satellite circling the earth above the atmosphere is as difficult as it would have been, some years before the Wright brothers flew at Kitty Hawk, to visualize the current uses of aviation in war and in peace. Some of the fields in which important results are to be expected are obvious; others, which may include some of the most important, will certainly be overlooked because of the novelty of the undertaking. The following considerations assume the future development of a satellite with large payload. Only a portion of these may be accomplished by the satellite described in the design study of this report.

The Military Importance of a Satellite – The military importance of establishing vehicles in satellite orbits arises largely from the circumstance that defenses against airborne attack are rapidly improving. Modern radar will detect aircraft at distances up to a few hundred miles, and can give continuous, precise data on their position. Anti-aircraft artillery and anti-aircraft guided missiles are able to engage such vehicles at considerable range, and the proximity fuze increases several fold the effectiveness of anti-aircraft fire. Under these circumstances, a considerable premium is put on high missile velocity, to increase the difficulty of interception.

This being so, we can assume that an air offensive of the future will be carried out largely or altogether by high-speed pilotless missiles. The minimum-energy trajectory for such a space-missile without [10] aerodynamic lift at long range is very flat, intersecting the earth at a shallow angle. This means that small errors in the trajectory of such a missile will produce large errors in the point of impact. It has been suggested that the accuracy can be increased by firing such a missile along the same general course as that being followed by a satellite, and at such a time that the two are close to one another at the center of the trajectory of the missile. Under these circumstances, precise observations of the position of the missile can be made from the satellite, and a final control impulse applied to bring the missile down on its intended target. This scheme, while it involves considerable complexity in instrumentation, seems entirely feasible. Alternatively, the satellite itself can be considered as the missile. After observations of its trajectory, a control impulse can be applied in such direction and amount, and at such a time, that the satellite is brought down on its target.

There is little difference in design and performance between an intercontinental rocket missile and a satellite. Thus a rocket missile with a free space-trajectory of 6,000 miles requires a minimum energy of launching which corresponds to an initial velocity of 4.4 miles per second, while a satellite requires 5.1. Consequently the development of a satellite will be directly applicable to the development of an inter-continental rocket missile.

It should also be remarked that the satellite offers an observation aircraft which cannot be brought down by an enemy who has not mastered similar techniques. In fact, a simple computation from the radar [11] equation shows that such a satellite is virtually undetectable from the ground by means of present-day radar. Perhaps the two most important classes of observation which can be made from such a satellite are the spotting of the points of impact of bombs launched by us, and the observation of weather conditions over enemy territory. As remarked below, short-range weather forecasting anywhere in the vicinity of the orbit of the satellite is extremely simple.

Certainly the full military usefulness of this technique cannot be evaluated today. There are doubtless many important possibilities which will be revealed only as work on the project proceeds.

The Satellite as an Aid to Research – The usefulness of a satellite in scientific research is very great. Typical of the outstanding problems which it can help to attack are the following:

One of the fastest-moving fields of investigation in modern nuclear physics is the study of cosmic rays. Even at the highest altitudes which have been reached with unmanned sounding balloons, a considerable depth of atmosphere has been traversed by the cosmic rays before their observation. On board such a satellite, the primary cosmic rays could be studied without the complications which arise within the atmosphere. From this study may come more important clues to unleashing the energy of the atomic nucleus.

Studies of gravitation with precision hitherto impossible may be made. This is possible because for the first time in history, a satellite would provide an acceleration-free laboratory where the ever present pull of the earth's gravitational field is cancelled by the centrifugal force [12] of the rotating satellite. Such studies might lead to an understanding of the cause of gravitation—which is now the greatest riddle of physics.

The variations in the earth's gravitational field over the face of the earth could be measured from a satellite. This would supply one very fundamental set of data needed by the geologists and geophysicists to understand the causes of mountain-building, etc.

Similarly, the variations in the earth's magnetic field could be measured with a completeness and rapidity hitherto impossible.

The satellite laboratory could undertake comprehensive research at the low pressures of space. The value of this in comparison with pressures now attainable in the laboratory might be great.

For the astronomer, a satellite would provide great assistance. Dr. Shapley, director of the Harvard Observatory, has expressed the view that measurements of the ultra-violet spectrum of the sun and stars would contribute greatly to an understanding of the source of the sun's surface energy, and perhaps would help explain sunspots. He also looks forward to the satellite observatory to provide an explanation for the "light of the night sky."

Astronomical observations made on the surface of the earth are seriously hampered by difficulties of "seeing," which arise because of variations in the refractive index of the column of air through which any terrestrial telescope must view the heavens. These difficulties are greatest in connection with the observation of any celestial body whose image is an actual disk, within which features of structure can be [13] recognized: the moon, the sun, the planets, and certain nebulae. A telescope even of modest size could, at a point outside the earth's atmosphere, make observations on such bodies which would be superior to those now made with the largest terrestrial telescopes. Because there would be no scattering of light by an atmosphere, continuous observation of the solar corona and the solar prominences should also be possible. Astronomical images could, of course, be sent back to the earth from an unmanned satellite by television means.

From a satellite at an altitude of hundreds of miles, circling the earth in a period of about one and one half hours, observations of the cloud patterns on the earth, and of their changes with time, could be made with great ease and convenience. This information should be of extreme value in connection with short-range weather forecasting, and tabulation of such data over a period of time might prove extremely valuable to long-range weather forecasting. A satellite on a North-South orbit could observe the whole surface of the world once a day, and entirely in the daylight.

The properties of the ionosphere could be studied in a new way from such a satellite. Present ionospheric measurements are all made by studying the reflection of radio waves from the ionized upper atmosphere. A satellite would permit these measurements to be extended by studying the transmission properties of the ionosphere at various frequencies, angles of incidence, and times. Reflection measurements could also be made from the top of the ionosphere. Since we now know that disruption of the ionosphere accompanying auroral displays is caused by the impact [14] of a cloud of matter from space, the satellite could determine the nature, and maybe the source of that cloud.

Biologists and medical scientists would want to study life in the acceleration-free environment of the satellite. This is an important pre-requisite to space travel by man, and it may also lead to important new observations in lower forms of life.

The Satellite as a Communications Relay Station – Long-range radio communication, except at extremely low frequencies (of the order of a few kc/sec), is based entirely on the reflection of radio waves from the ionosphere. Since the properties of the earth's ionized layer vary profoundly with the time of day, the season, sunspot activity, and other factors, it is difficult to maintain reliable long-range communication by means of radio. A satellite offers the possibility of establishing a relay station above the earth, through which long-range communications can be maintained independent of any except geometrical factors.

The enormous bandwidths attainable at microwave frequencies enable a very large number of independent channels to be handled with simple equipment, and the only difficulty which the scheme appears to offer is that a low-altitude (300 mile) satellite would remain in the view of a single ground station only for about 2,100 miles of its orbit.

For communications purposes it would be desirable to operate the satellites at an altitude greater than 300 miles. If they could be at such an altitude (approximately 25,000 miles) that their rotational period was the same as that of the earth, not only would the "shadow" effect of the earth be greatly reduced, but also a given relay station could be associated with a given communication terminus on the earth, so that the communication system problem might be very greatly simplified.

[15] An idea of the potential commercial importance of this development may be gained from the fact that the ionosphere is now used as the equivalent of about $10,000,000,000. in long-lines, and is jammed to the limit with transmissions.

[16] **The Satellite as a Forerunner of Interplanetary Travel** – The most fascinating aspect of successfully launching a satellite would be the pulse quickening stimulation it would give to considerations of interplanetary travel. Whose imagination is not fired by the possibility of voyaging out beyond the limits of our earth, traveling to the Moon, to Venus and Mars? Such thoughts when put on paper now seem like idle fancy. But, a man-made satellite, circling our globe beyond the limits of the atmosphere is the first step. The other necessary steps would surely follow in rapid succession. Who would be so bold as to say that this might not come within our time?...

[211] 14. **Possibilities of a Man Carrying Vehicle**

Throughout the present design study of a satellite vehicle, it has been assumed that it would be used primarily as an uninhabited scientific laboratory. Later developments could alter its capabilities for use as an instrument of warfare.

However, it must be confessed that in the back of many minds of the men working on this study there lingered the hope that our impartial engineering analysis would bring forth a vehicle not unsuited to human transportation.

It was of course realized that 500 lbs. and 20 cubic feet were insufficient allotment for a man who was to spend many days in the vehicle. However, these values were sufficient to give assurance that livable accommodation could be provided on some future vehicle.

The first question to be considered in determining the possibility of building a man carrying vehicle is whether prohibitively high accelerations can be avoided during the ascent. The V-2 gave hope that this was possible. Our own studies have likewise shown that the optimal accelerations do not exceed about 6.5g. A man can withstand such acceleration for the periods of time involved (several minutes) if he is properly supported with his trunk lying normal to the directions of the acceleration. In Chapter 8, it will be remembered, the analysis showed that the performance could be improved a small amount by throttling each rocket motor during the letter portion of its burning period in order to reduce the structural loads. Under these conditions, the maximum accelerations could be profitably reduced to about 4 g. All these findings confirm [212] that ascent offers no insurmountable obstacle to the construction of an inhabited satellite vehicle.

Next we consider the safety and welfare of the man after the vehicle has been established on the orbit. Popular fiction writers have devoted considerable thought and ingenuity to means of furnishing him with air, food and water. The most ingenious of these solutions is that of the balanced vivarium in which plants and man completely supply each others needs. Leaving these problems to the inventors, we ask ourselves the engineering questions of whether we can provide livable temperatures and a reasonable protection against meteors. In Chapter 11 we have seen that the answers are tentatively in the affirmative.

Lastly we consider the problem of safely returning the vehicle's inhabitant to the surface of the earth. In Chapter 12, we have seen that, with reasonable area wings, we can control the descent sufficiently to avoid dangerously high temperatures. These same wings are adequate to accomplish the final landing on the earth's surface.

The above thoughts are far from final answers on this problem. However, they do give a note of assurance that the hope of an inhabited satellite is not futile....

Document II-3

Document title: J.E. Lipp, R.M. Salter, Jr., and R.S. Wehner, et.al., "The Utility of a Satellite Vehicle for Reconnaissance," The Rand Corporation, R-217. April 1951, pp. ix, 1-21, 28-39.

Source: National Security Archive, Washington, D.C.

After Rand had recommended advanced study into the uses of satellites for strategic reconnaissance in November 1950, the Air Force authorized Rand to undertake further research. The results of a Rand study on "The Utility of a Satellite Vehicle for Reconnaissance" were presented to the Air Force in April 1951. They demonstrated the viability of the concept and recommended further research. This recommendation eventually led to the much larger "Project Feed Back" [II-7] in 1954. These excerpts from the over-135-page report contain a general discussion in terms of orbits and instruments of the feasibility of satellite reconnaissance.

[ix]

Summary

Utility of an earth-circling space vehicle as a reconnaissance device is considered here in detail. A satellite (initially placed on its orbit by rocket power) which televises ground scenes and weather information to surface receiving stations is investigated. Particular attention is given to the television, communication, and electrical-power-supply problems, since these are the major determining factors in payload utility of a reconnaissance satellite. Some important corollary aspects namely attitude control and equipment reliability, are also discussed.

In order to round out the study, performance and weight estimates of the rocket vehicle required to carry a television payload are included.

The general conclusion of the report is that television satellites are feasible and that they would be useful if built and operated. Various essential lines of research in television, auxiliary power, and reliability are indicated....

[1]

Introduction

The basic feasibility of satellites from the point of view of rocket performance was considered in a previous group of RAND reports, Refs. 3 through 14. That investigation pointed to several important conclusions. First, the engineering of a rocket vehicle of adequate performance for use as a satellite would require but minor development beyond the then-existing technology. Secondly, the payload would have to be small (not more than 2000 lb) to keep the gross weight within reason; hence destructive payloads are not likely to be economically worthwhile for many years to come. Thirdly, returning the vehicle to earth intact would be difficult and should not be attempted in the early versions.

The above factors indicated that the payload would be restricted to instrumentation and communication equipment and prompted the RDB (Technical Evaluation Group) and the Air Force to request that further attention be given to the question of utility. RAND's effort since 1947 on the satellite study has been closely tied to the payload—its description and military usefulness. Most attention has been directed toward reconnaissance, since that is a field in which a satellite may very well show advantages over other types of vehicles.

It now appears fortunate that reconnaissance was selected for the first payload investigation. As will be seen later in the report, pioneer reconnaissance (general location and determination of appropriate targets) and weather reconnaissance are suitable with the resolving power presently available to a satellite television system. These two classes of reconnaissance have also been growing in importance to the Air Force because of the vastness of Russia and the difficulty of gaining information by conventional means.

To explore further the possibility of reconnaissance by means of a satellite, it is necessary to investigate the various constraints imposed in conducting such an observation from a remote, unattended vehicle.

The first step in such an analysis logically considers the movement of the satellite as a vehicle with respect to the targets to be viewed. Consideration must be given to the degrees of freedom at our disposal in the type and position of orbits and to the frequency of the satellite within the orbit. This approach, from a macroscopic standpoint, gives rise to information on how often and under what conditions the satellite can be placed over a given target. This is discussed in Section I, "Satellite Orbits and Ground Coverage."

Naturally following this step is the microscopic inquiry into the feasibility of viewing a target from the satellite. Television has been selected as the only practical way known at present for transmitting back to earth that which can be seen from the vehicle. Thus an evaluation of television-camera-equipment capabilities, along with a discussion of associated problems of transmission of the picture, is presented in Section II, "Reconnaissance by Television."

[2] Moreover, since there is an intimate interdependence between the type of reconnaissance desirable and the most fruitful way of obtaining such reconnaissance, some simultaneous consideration should be given to the presentation of satellite position (orbits), television scanning, and picture quality. This may be found at the conclusion of Section II.

The remaining problems can be classed as attendant ones peculiar to obtaining remote television broadcasts from the satellite. In order to scan the surface of the earth with the television camera, the vehicle must be properly oriented (attitudewise) with respect to the earth's surface. This is covered in Section III, "Orbital Attitude Measurement and Control."

The television and attitude control equipments require electrical energy that must be supplied by an auxiliary powerplant. A discussion of this powerplant, as well as the estimated power and weight requirements it must meet, is given in Section IV, "Auxiliary Powerplant."

Section V, "Reliability of the Satellite," includes an analysis of the anticipated reliability of the television and auxiliary equipment. This is a particularly important problem, since the equipment must operate automatically for a long period in an inaccessible location.

Finally, the characteristics of the vehicle itself necessary to place the television payload in a given orbit around the earth are presented in Section VI.

The several appendixes furnish correlative data and extensions of the remarks concerning some of the more salient features resulting from the study of the technical feasibility of utility of satellites for reconnaissance.

[3] I. Satellite Orbits and Ground Coverage

This section presents a general discussion of the pertinent facts about orbits which are essential to the utility of a satellite as a reconnaissance vehicle and of the problems concerning the establishment of a rocket-vehicle satellite on an approximately circular oblique orbit relative to the earth. Since the primary utility aspect considered is reconnaissance, the effect of orbits on scanning (i.e., viewing) angles, as well as some discussion of the limitations imposed by optical and radio transmission requirements, are included.

Orbits Generally

A satellite is defined as an attendant body revolving about a larger one; a moon and a man-made object revolving about the earth are thus satellites. The earth itself is a satellite of the sun. The shape of a satellite orbit, which can be either circular or elliptical, is dependent principally on the initial conditions of velocity, position, and direction of motion.

A circular orbit is of course the most desirable for an artificial satellite. Any marked deviations or eccentricity would cause some portion of the flight path to pass through more dense atmosphere and thus decrease the endurance of the satellite (for the likely range of orbital altitudes).

In order to remain on an orbit, the velocity of a satellite must be such that its centrifugal force is sufficient to overcome the earth's gravitational forces upon the satellite at the orbital altitude. Initial trajectory control is required to be such that the velocity is at least that necessary for a circular orbit[298] at the design altitude, and the path angle is within 1/2°.(7) These limits are attainable with present control equipment.

RAND's previous studies were devoted primarily to equatorial orbits, which are still of prime interest for preliminary, experimental satellite flights. However, it is obvious that a reconnaissance satellite must be placed on an oblique orbit[299] to view targets of military interest most efficiently.

[4] **Review of Orbital Features**

Figure 1 illustrates the orbit of a satellite placed on a circular path. Such a path, *if unperturbed,* would maintain a fixed orientation in space (in this case, as in all others to be discussed here, the centers of the satellite's path reference frame coincide with that of the earth's). Thus the satellite reference frame would move around the sun with the earth but would not be affected by the earth's own rotation. Further, the position of the satellite orbit relative to the sunny side of the earth would change with the earth's seasons.[300] Figure 2 depicts this relative change of orbital position for a hypothetical satellite whose orbit is undisturbed by external influences.

Orbital Regression and Resultant Periods

As pointed out in Ref. 14, the orbit is affected by the presence of other astronomical bodies, such as the sun and the moon, and by the shape of the earth. The effect of the sun and the moon on a satellite orbit is nearly identical with their effect upon free-water surfaces of the earth (tides) and results in approximately a 3-ft orbital variation.

The oblate shape of the earth, however, exerts a much larger influence on the satellite rocket. The earth's polar diameter is about 25 mi less than its equatorial diameter. Although a polar orbit will have a vertical variation of approximately 1 mi (an orbit around the equator will have a negligible variation), this effect of the earth's shape is not of direct concern. The interesting and important effect is a corollary of the polar [5] perturbation, namely, a significant regression of the nodes[301] when the satellite orbit is oblique. This regression is similar to the precession of a gyroscope caused by externally applied torques.

Further, the regression period[302] of the satellite orbit will vary, depending on the orbital altitude and obliquity. After the method of Ref. 14, the orbital regression periods relative to the sunny side of the earth and to celestial space are plotted as functions of altitude and orbital angle in Fig. 3. For useful reconnaissance orbits, 45° to 60° obliquity and 350 to 500 mi altitude, the change in period relative to the earth is not great.

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[298] Velocities less than that required for a circular orbit obviously prevent the vehicle from establishing the prescribed orbit; hence the satellite will either fall to earth or assume an elliptical orbit which will cause marked altitude variations. Velocities greater than required yield less disastrous, but also undesirable, elliptical paths.

[299] In this report an orbit will be designated by the degrees of an angle between it and the equator. An alternative but equivalent description is the maximum latitude to which the orbit is tangent. Thus a 0° orbit is equatorial, a 90° orbit is polar, and a 56° orbit is 56° oblique to the equator and tangent at 56° latitude.

[300] An exception here is an orbit around the equator where this seasonal change is irrelevant.

[301] Regression of the nodes may be visualized as a westerly rotation of the line of intersection (nodal line) between the satellite's orbital plane and the earth's equatorial plane (see Figs. 1, 4, and 5).

[302] Regression period, as used here, is the time required for the intersection line (see footnote above) to make one complete revolution relative either to the sunny side of the earth or to celestial space, as applicable (see Fig. 4).

For illustrative purposes only, a 56° oblique orbit, approximately the latitude of Moscow, will be studied for most of the balance of this discussion. Figure 4 depicts the nodal regression for a vehicle on such a path. It may be seen in this illustration that the position of the orbit relative to the sunny side of the earth changes not with the earth's seasons, but much more rapidly; for this particular orbit, the period relative to the earth is 70 days rather than a year.

Under these conditions, the satellite can see a given target in the daytime only during alternate 35-day intervals regardless of whether the satellite circles the earth once a day or a thousand times; Fig. 5 amplifies this point. Thus a single satellite cannot [6] give a continuous record of daytime viewing of a particular target, but only during alternate 35-day periods. If continuous chronological daytime coverage is desired for longer periods, a minimum of two vehicles would be required. Further, if contrast requirements exclude twilight intervals, then three satellites operating on 8-hr shifts, with paths as shown in Fig. 6, are necessary.

Altitude, Velocity, and Duration

So far, discussion has been centered on the path of the satellite in its orbit. Its speed and altitude will now be considered. Figure 7 gives a plot of the required satellite velocity as a function of altitude above the earth for a nearly circular orbit. Since this velocity is independent of the earth's rotation, a satellite launched eastward gains by the component of the earth's peripheral speed in that direction. Figure 7 also shows the number of satellite revolutions per day as affected by orbital altitude.

The duration of an orbiting vehicle depends on the amount of atmosphere tending to slow it down. This in turn means that the higher the altitude, the longer the satellite [7] can stay up.

Figure 8, taken from Ref. 3, gives anticipated duration as a function of altitude. At a 100-mi altitude the vehicle will be pulled to earth in less than one revolution because of the atmospheric drag. At 350 mi the duration is about 2 years. At 500 mi the satellite will stay up around 50 years; at 600 mi, several centuries. From this standpoint alone, it is desirable to use as high an altitude as possible. Also, the range of line-of-sight[303] radio transmission increases with altitude. Counterbalancing these factors is the greater size of the satellite required to put a given payload on an orbit at higher altitudes (e.g., 10 to 20 per cent higher gross weight is required to increase altitude from 350 to 500 mi; see Fig. 40, page 77). Another deterrent factor is the increased size and weight of camera equipment necessary to scan the earth from higher altitudes, which requires higher resolving power for an equivalent picture. Therefore, the desirable altitude will represent a compromise between these opposing features but will probably lie between 350 and 500 mi. For purposes of consistency, a 350-mi altitude will be used in the remainder of this report, except where altitude is considered as a variable.

Effect of Orbital Altitude on Ground Coverage and Related Problems

At orbital altitudes of 350 to 500 mi, the satellite circles the earth fifteen to fourteen times a day (see Fig. 7). The satellite tracks cross the equator at intervals of 24° to [8] 25° longitude or, roughly, there are 1700 mi (measured east-west at the equator) between tracks for the 350-mi altitude.

At 56° latitude, for example, this interval is about 800 mi; near the tangent latitude the tracks recross each other several times. Figure 9 indicates the tracks for a satellite at an orbital altitude of 350 mi and at an orbital angle of 56°. Also shown is the average daytime coverage during the daylight "season" with a 400-mi optical scan to either side of the satel-

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[303] Only line-of-sight transmission can be used because high-frequency waves are necessary for television equipment. Also, long radio wavelengths will be adversely affected by the ionosphere; for instance, reflection by the Heaviside layer will prevent such wavelengths from reaching the earth rather than to increase their range.

lite (800-mi optical-scanning band); the light-green area shows targets covered once a day; medium green, those covered twice; and dark green, those covered three or more times. White areas (below the tangent latitude) are those viewed less than once a day; as indicated in the figure, for the assumed satellite orbit, coverage in any one day is not complete below 30° N. latitude.

The 800-mi optical-scanning band at 350 mi altitude represents approximately a 94° included scanning angle, i.e., a 47° scan to either side of the vertical. The included angle of the horizon is 135°, but the value of pictures taken beyond 45° on either side of vertical is questionable. This point is shown schematically in Fig. 10, which also gives a plot of horizon angle as a function of altitude. A discussion of the effects of scanning angle, as well as those of the orbital inclination, upon the minimum resolvable surface dimension is presented in Appendix I.

Proper initial selection of the orbital altitude would enable the satellite to make an integral number of revolutions for one revolution of the earth relative to the orbital plane (not necessarily per 24-hr day, since the orbital plane regresses[304]). Integral [9] numbers of satellite revolutions every other (24.3-hr) day, every third day, etc., are also possible. Such orbital conditions, however, cannot be made accurately enough with present control equipment to afford the same trace on the earth's surface day after day. Thus a drift can be expected so that the satellite will come within a few miles of its track on the previous day (or the previous alternate day, etc.). The significant fact is that by adjusting an orbital period so that it is nearly integral on alternate days, one can obtain, the following day, a picture in the center of the camera scan of a target which was on the periphery the day before (see Fig. 9), except, of course, near the tangent latitude, in which region still greater amounts of overlap are obtained.

As mentioned earlier, one factor indicating the desirability of a 500-mi altitude is the need to receive the satellite's television broadcasts by stations sited either in friendly territories or on ships. Figure 11 shows the area of reconnaissance interest which would be covered by transmission ranges of 1396 and 1743 mi with 5 stations and 2000 mi [10] with 4 stations (see Fig. 22, page 30, for range as a function of altitude and elevation angle). Transmission must be "line-of-sight" because of the required radiation frequencies. It is estimated that the maximum range for acceptable transmission[305] from a 350-mi altitude is about 1400 mi. At this range, 5 stations would be required to pick up Asiatic observations, but about 15 per cent of the USSR, a significant portion near 105°E longitude, would be left out. Increasing the satellite's altitude to 500 mi affords (on the same basis) a range of approximately 1750 mi. With this range and the same 5 stations, the unobserved area is reduced to a small amount.

With a 2000-mi range (not shown), the unobserved area would be eliminated. However, by accepting a small unobserved area near 95°E longitude, 4 sea-borne stations could be employed. At this latter range, the orbital altitude required for equivalent clarity of the transmission exceeds 600 mi (see Fig. 22, page 30); it may be possible to attain a 2000-mi range from a 500-mi altitude, although some uncertainty and signal distortion would occur in the 100- to 250-mi extremity.

The possibility of eliminating so-called unobservable areas by using delayed broadcasting becomes apparent. It is well to note, however, that the number of frames to be filed would cause the transmitting device to be so bulky and complex that this method does not appear to warrant further investigation at the present time.

[11] The effect of different altitudes upon target viewing, as well as upon television camera resolution and contrast, is discussed further in the next section.

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[304] The period for a 350-mi altitude, 56° orbit is 24.31 hr, which is termed a day throughout the remainder of this discussion.

[305] It is assumed that a minimum elevation angle (above the horizon) of 5° be employed for completely acceptable signal reception.

Summary

To summarize briefly, the orbiting characteristics are critically dependent on the altitude; a substantially circular orbit is most desirable. Although equatorial orbits are desirable for test purposes, oblique orbits are necessary for meaningful reconnaissance. For example, a 350-mi altitude, 56° orbit, in combination with an 87-day regression period of the orbital plane relative to celestial space and to the seasonal motion of the earth around the sun, will afford daylight views of a specific target during alternate approximately 35-day intervals (one-half the 70-day regression period relative to the earth). Completely target-system coverage, from the eastern to western limits of Russian-controlled territory, will reduce the unproductive interval by about one-half.

[12]

II. Reconnaissance by Television

In the first section, the macroscopic aspects of satellite reconnaissance have been discussed, namely, the placement of the vehicle in appropriate orbits for bringing targets of military significance under scrutiny. The means of viewing and transmitting these scenes to ground stations will now be weighed. At the present time, it is felt desirable to consider only remote transmission of picture information by high-frequency radio waves. Other possible alternatives, such as using a conventional aerial photographic camera and returning the satellite to earth on command, appear to involve difficulties that would make early versions of the satellite impractical.

Two systems, television and photographic facsimile transmission, are available for consideration for photographing and sending on reconnaissance data. The latter system uses a camera film to record temporarily scene information; this film is then scanned electronically and the impulses transmitted as in the standard "wirephoto" system. A re-usable film must be employed because, otherwise, roughly $^3/_4$ ton of camera film would be required per month's operation. Since we know of no re-usable film (or other less bulky storage strip) under development, the photographic facsimile system will be ruled out for the present; future requirements, such as those for delayed picture transmission, may cause reconsideration of this system.

The use of television emerges, then, as of prime import in viewing and sending to ground stations reconnaissance information for recording and for evaluation. The ability of such a system to accommodate reconnaissance requisites will be considered in detail, both for viewing weather and for observing ground targets. Each of these latter types of reconnaissance has its own peculiar needs, which will be discussed first in this section.

The effect of reconnaissance requirements on camera equipment is considered next. It will be demonstrated that daytime viewing is possible, but nighttime light levels are too low for practical televising. The discussion of daytime viewing is then expanded to include specific numbers of the minimum resolvable ground dimensions as functions of scene contrast, frame speed, and the number of lines per inch resolution of the camera. A correlation between the ground area to be covered and the frame speed, and the need for an optical-scanning system, are determined. The above investigation is of a general nature and would apply to any "camera," whether it uses film, is a television tube, or is the human eye.

Logically following the above discussion, the television camera tubes are examined in relation to the foregoing optical parameters. The commercial Image Orthicon and the Vidicon tubes are shown to be within the realm of possibility for satellite viewing.

A discussion is then presented of the television camera system in context with the reconnaissance requirements and of the various combinations of characteristics that could be employed to produce an over-all optical-scanning system for use in both weather [13] and terrestrial reconnaissance. Also included are actual photographs of a simulated ground scene by a commercial Image Orthicon camera. It is shown that even by present commercial television standards, useful scene information can be obtained.

The transmission of the televised scenes, the necessary television mechanisms, the effects of signal wavelength, the position of the satellite relative to ground stations, and the possibility of enemy interception and jamming are included in the next subsection. Following this is an analysis of the reception and presentation of the televised signal as would be done by the ground monitoring stations.

Weight estimates and power requirements for the satellite television camera-transmitter system are then presented. For a more complete analysis of the television system's design considerations, see Appendix II.

Reconnaissance Requirements

To obtain any useful information from altitudes of 350 to 500 mi appears at the outset to be an extremely difficult operation. It is the purpose here to examine the constraints imposed on the television system in conducting reconnaissance of a worthwhile nature. Two types of observation will be considered: weather and terrestrial.

Weather Reconnaissance

Reference 1 offers a far more complete analysis of the requirements for weather reconnaissance than can be given here. However, in this report it is desirable to discuss briefly these requisites for the purpose of continuity. Information in Ref. 1 reveals that details of cloud structure as small as several hundred feet in dimension may possess meteorological significance. For weather observations, resolutions as poor as 500 to 1000 ft can be utilized, although a better minimum resolvable dimension would be 200 ft. This latter resolution is ample to determine a major portion of the characteristics necessary to predict weather. At this resolution, orientation and structure of clouds, direction of winds, and presence of fronts can be seen.

To explore deeply into the problem, the prevailing contrasts of weather scenes must be examined. For weather reconnaissance, the contrast is a function of the albedos[306] of various types of clouds and of the background. An albedo of 0.8, commonly given for average cloud formations (see Fig. 49, page 94), is used with the albedos of the various surface backgrounds to determine the degree of contrast available. Figure 12 shows graphically that contrasts of 50 per cent or more are produced by virtually all ground-surface background conditions except that of fresh snow; also shown in Fig. 12 is a similar graph for smooth sea surfaces and various solar elevations.

An additional feature of weather reconnaissance is the need to encompass the entire area in question with a daily observational coverage.

At the risk of being premature in describing the television system, a few illustrative remarks will be made here. An optical-scanning system viewing a band on the earth's surface of 800 mi width and taking frames, or pictures, at the rate of ten per second [14] will be assumed. A standard Image Orthicon television camera with appropriate optics at the 10 frame/sec speed and for the pertinent contrasts prevailing in weather scenes will resolve a dimension of 200 ft. Therefore the conclusion is that such a system could be completely adequate and useful for meteorological observational purposes.

Terrestrial Reconnaissance

The requirements for viewing targets—of military significance—on the ground are now considered. Taking the cue from the above discussion, it is apparent that a 200-ft resolution can be easily attained at prevailing weather contrast levels (which are nearly all at contrasts above 20 per cent) and that a complete daily area coverage can be expected with this system. However, that contrasts of less than 20 per cent do exist on military targets and that a 200-ft resolution will not be completely adequate will be discussed subsequently.

[306] Albedo is the ratio of the amount of light reflected from a prefectly diffuse surface to the total light falling upon it.

Figure 13 depicts contrasts that may be expected from various military targets against representative backgrounds. Year-round observation from the satellite will yield a number of pictures of a given target during the different seasons, possibly with informative [15] results. For example, an asphalt airstrip and its adjacent ground cover may have no albedo difference, hence no contrast, during the spring-to-fall period; during early winter, however, a thin layer of snow on the adjacent ground cover, but melted or removed from the airstrip, may result in contrasts as high as 85 percent. Furthermore, continued observations throughout seasonal ground-cover variations will tend to reduce the effectiveness of camouflage. It is readily apparent that the conditions for taking such pictures are dependent on the number of clear days during the period the satellite passes over a specified military target. However, if a continuous chronological record is broadcast from the satellite for a year, it is reasonable to expect that each target will be seen at some time on a clear day.

The second criterion for terrestrial reconnaissance is, of course, the allowable minimum resolvable surface dimension. The ultimate choice of the figure for this dimension will remain with intelligence personnel skilled at interpreting information. The 200-ft resolution is probably adequate for ferreting out major airfields and for noting the presence of large highway or railroad right-of-ways (even though lateral dimensions may be [16] considerably less than 200 ft). Large factory buildings will be seen, although their exact shape may be indeterminable. Square buildings of 200 ft on a side will tend to be confused with round fuel-storage tanks of similar size.

A 50-ft resolvable dimension will afford considerable improvement in detailed information. The structure of urban areas can be determined. Large aircraft can be identified, as can gun emplacements, revetments, etc.

Assessment of bomb damage will probably require even better resolving power (perhaps as low as 10 ft) and may well be beyond the scope of the satellite system.

From the above discussion, it is seen that the previously assumed camera and scanning system is, on the basis of minimum resolvable surface dimension, useful and adequate for pioneer terrestrial reconnaissance. However, such a system is inadequate for reconnaissance concerned with detailed target identification. The ways in which detailed reconnaissance can be achieved are discussed later in this section, but it can be stated briefly that either a fundamental improvement in the television camera tube or a reduction of the observable area on the ground—so that complete coverage is not made every day but every 10 days or so—must be made.

Summary of Reconnaissance Requirements for the Television System

It has been shown that minimum resolvable dimensions of 50 to 500 ft are acceptable, depending on the type of observations made. Thus the television camera must be capable of resolving dimensions on the ground—or near the ground for weather—of the same order of magnitude measured in feet as $^1/_{10}$ to 1 times that of the optical range measured in miles. This resolving power, 0.001° to 0.01°, implies a small angle of view, as will be demonstrated later.

Optical scanning over a reasonably wide swath on the earth's surface will require (in conjunction with the small field of view) a large number of frames in a given time interval—of the order of 10 to 30 frames/sec.

Contrast levels of 20 per cent or higher will normally be needed.

Nighttime and Color Television

So far, discussion has been predicated on the conditions that would prevail in taking black-and-white pictures in the daytime. For black-and-white shots at night, the same scene contrasts would be expected, *but the overall scene brightness would be considerably reduced.*

The use of television for transmitting scenes viewed by a satellite at night, while physically possible (see Appendix II), is considered impractical. A camera system sufficiently flexible to accommodate both daytime and nighttime viewing not only would be complex, but also would require an f/0.6 optical system, which in turn would require a 30-in. aperture for a 20-in. focal length (as compared with a 2-in. aperture for daytime viewing). The total size and weight of such a device as presently conceived would be prohibitive.

Although color television has lower resolution than black-and-white video, the use of color television might result in more effective photo interpretation. For example, a [17] black airstrip surrounded by green grass can readily be identified in color even though its black-and-white contrast may be zero. It is doubtful, however, that color television could counteract camouflage because the TV camera does not see more of the infrared spectrum than does the human eye. Size, weight, and complexity of such a system do not warrant its further investigation at this time.

Hence the remainder of the section will be devoted to black-and-white television, with viewing done only in daylight.

Optical System

Resolving Power and Contrast

Resolvable detail in photographs made by satellite television (or any other type of camera) is dependent on brightness, scene contrast, exposure time, and geometrical factors. It is also a function of the inherent resolution of the camera itself. A television camera is characterized by the number of television lines per inch (equal to roughly twice the number of optical lines per inch) and this parameter is an index of the tube's resolution.[307]

In Table 12, on page 102, may be found an enumeration of the minimum surface dimensions, δ, resolvable by day for various contrasts, TV lines per inch camera resolution, and frame frequencies and for the various required optical parameters of focal length and aperture size. Along with δ, the relative power, P, required for picture transmission is also listed.

A digest of Table 12 is given in Table 1, below, which shows what can be accomplished with an f/10, 2-in. camera aperture, 20-in. focal length camera, operating at a frequency of 10 frames/sec.

[18] It is expected that the Image Orthicon camera tube (see page 20) will give resolutions of the order of 1000 TV lines/in., which means that with the above optical system, a 200-ft minimum resolvable surface dimension can be anticipated for contrasts as low as 20 per cent.

By changing the camera optics to restrict the field of view and by increasing frame frequency, it may be noted from Table 12, page 102, that considerable improvement in ∂ can be wrought. Values as low as $\delta = 40$ ft (at 25 per cent contrast) are obtained with the same TV tube resolution of 1000 TV lines/in.

The Optical-scanning System

The f/10, 20-in. focal length optical system will view, in a single frame, a ground-projected square area of 17.5 mi on a side directly under the satellite. (Figure 15, page 22, shows an equivalent southwest sector of Los Angeles which would be taken by one frame.) A 47° viewing angle will cover a ground-surface width of 800 mi from an altitude of 350 mi. Because of the curvature and obliquity of the surface of the earth, as shown in Fig. 10, page 9, the ground area seen by the optical system at 47° (the angle measured from the vertical) is nearly doubled, the transverse ground dimension being about 35 mi. Consequently, 39 to 40 frames are needed to view the 800-mi band in one transverse sweep.

During this same time, the satellite is moving forward 17.5 mi at a speed of approximately 5 mi/sec, which allows about 3.5 sec/transverse sweep and, for 39 to 40 frames,

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[307] Resolution by a photographic camera is commonly defined by the minimum spacing of lines that can just be discerned in a photograph by the camera. In television the index is based on the distance from one of the lines to the center of the intervening space between the lines (this distance being called one television "line"). Thus one optical line is equivalent, approximately, to two television lines. It should be noted that a single index of this type is inadequate to describe fully the quality of a camera, and it is assumed in this report that the television cameras have good characteristics with respect to sensitivity as a function of the various sizes of the objects viewed.

checks generally with the previously assumed 10 frames/sec.

The motion of the optical scan must be such that the area under observation is "stopped" relative to the photocathode, which requires indexing between successive frames in the transverse sweep, and the fore-and-aft motion to compensate for the satellite's forward motion.

Transverse and longitudinal camera positions relative to the satellite structure are shown in Fig. 14 as functions of time per frame. Also shown is a proposed scanning system. It may be possible to synthesize this complex motion by an appropriately designed, continuously rotating prism (not shown).

Satellite attitude control of yaw, pitch, and roll, relative to "stopping" the picture, is discussed in Section III. Further discussions of the scanning angle, of the orbital inclination, of the frame frequency, and of the resolvable surface dimensions are presented in Appendixes I and II.

The Television Camera

The task of televising a ground scene from a satellite differs from the ordinary video pickup problem in three principal ways: (1) as just indicated, a high-resolution, scanning, optical system is required, (2) the equipment must operate over a relatively [19] long period of time from a remote, unattended station, and (3) each frame is a completely different picture. This latter subject is discussed further under "Reliability of the Satellite," Section V, page 63. It is probable that presently available television-tube resolutions are adequate for preliminary reconnaissance of either weather or terrain; however, it is anticipated that the normal trend in television research will yield higher resolutions by the time a satellite requires such a system.

[20]

Limiting Resolution of Pickup Tubes

The basic elements of modern television camera tubes are (1) a photosensitive target, upon which the viewed scene is projected and reproduced as a pattern of static electric charges, and (2) an electron beam which scans the charge pattern on the target, reading and erasing it and transforming it into a time-varying electrical signal. The scanning beam is usually made to cover the target in a series of horizontal lines or in two interlaced series of lines, and the beam moves at such speed that the entire picture, or frame, is scanned in a small fraction of a second. Present commercial television practice employs 525 scanning lines/frames at a rate of 30 frames/sec, and the pickup-tube resolution is therefore limited to 525 TV lines/frame (or slightly more than 250 optical lines). A more fundamental limitation on the resolution of a pickup tube than the number of scanning lines is the finite size of the cross section of the scanning beam or the finite size of the elements composing the target, whichever is larger. It is of interest to note that the scanning-beam sizes in electron microscopes is an order of magnitude smaller (10^{-3} min spot size).

The resolution of the best available photoemissive pickup tubes (Image Orthicons) is limited by target structure. This tube uses a thin two-sided target, upon one side of which the charge pattern representing the scene televised is deposited by secondary emission. Photoelectrons from the primary cathode, or photo-cathode, of the tube focus upon the target and impinge upon it under conditions which result in a high secondary emission ratio; each incident photoelectron ejects several secondary electrons from the target face, the charge pattern on the target being correspondingly more intense than that on the photocathode. These secondary electrons are collected by a grid of very fine wire mounted close to the target on the photocathode side. The grid effectively breaks up the otherwise continuous target surface into a mosaic of elements of size corresponding to its mesh spacing. In commercial Image Orthicons, the grid contains slightly more than 500 mesh spacings/linear in., and the limiting resolution is therefore about 500 optical lines/in., or 1000 TV lines, of target surface. Experimental Image Orthicons have been made with fine grid meshes, corresponding to limiting resolutions better than 1500 TV lines/in.

Resolving power of present photoconductive pickup tubes (Vidicons) is limited by the cross-sectional size of the scanning beam. The photoconductive process is inherently more sensitive than photoemission and no preliminary amplification of the target charge pattern by secondary emission is required; no collecting grid is involved and the Vidicon target is essentially continuous. The smallest resolvable target element is therefore determined approximately by the half-power width of the scanning beam (at the target). In a recently developed Vidicon, this beamwidth is about 0.00125 inclusive, corresponding to a limiting tube resolution of about 1600 TV lines to an *inch.* However, this does not mean that the present Vidicons have a higher resolution than do Image Orthicons. On the contrary, the present target size of the Vidicon is considerably less than 1 in., and the number of TV lines to a *frame* is less than in the Image Orthicon. Major difficulty would be experienced in attempting to increase the Vidicon target sizes to about an inch (as in the Image Orthicon) because of the increasing electrical capacitance of [21] the target. Nevertheless, this does not preclude the possibility of using several Vidicons to replace one Image Orthicon, with the attendant reduction of reliability.

The possibility of a really significant improvement in the limiting resolution of an Image-Orthicon-type pickup tube is regarded as remote, because of the great difficulties inherent in constructing and mounting collecting screens composed of conductors much smaller than about one-thousandth of an inch in diameter. Significant improvement seems more likely in the case of photoconductive tubes, since much narrower scanning beams are theoretically possible by improvement of the optical design of the electron gun and of the focusing and scanning fields. But a limit will soon be reached at which further reduction in beam spot size results in no further improvement in resolution and at which resolution will be limited by the finite conductivity of the target. This follows from the fact that the thickness and conductivity of the target must be such as to allow for dissipation of the charge pattern by conduction through the target in a period not much greater than the frame time; if the conductivity is such that it permits this desired charge motion, it will also (assuming isotropic target material) allow charges to move laterally over the target face so that even an initial point charge will be spread over a circle of diffusion, the diameter of which will ultimately determine the limiting resolution regardless of the spot size of the scanning beam.

It appears probable therefore that 1500 TV line/in. is a reasonable maximum value for the limiting resolution of pickup tubes for some time to come, and that a practical value for unattended operation of present tubes in a satellite vehicle might well be considerably less than this, say about 1000 TV lines/in....

[28] **Transmission of the Television Pictures**

On the basis that the satellite's television camera system can collect valuable information, it is necessary to transmit the pictures from the satellite to surface receiving stations and to record and portray the pictures in useful form. The range at which satellite signals can be received by ground stations will be discussed first, since this [29] range affects the disposition of the stations and ultimately determines the completeness of coverage of enemy territory by direct broadcast to receiving points in friendly territory. Possible locations of receiving stations was discussed in Section I.

Next, consideration will be given to the tracking system and to the effects of switching the television broadcast reception from one station to the succeeding one. The following subsection is devoted to the antenna gain and to the power required, since these are intimately related to the system employed to track the satellite. Logically following this there is a discussion of the proper choice of wavelength. Finally, the possibilities of interception and jamming of the television signal will be considered.

Before continuing further, however, it is felt desirable at this point to outline the over-all television system. Figure 21 is a block diagram of the proposed system. Component parts will be (and have been) described as they appear in the discussion.

Range of Transmission

There are quite good reasons for not attempting to track or communicate with the satellite from surface stations when its angular elevation above the horizon is less than [30] 5°.(10) Consequently, this value of the elevation angle has been considered as determining the maximum range over which completely acceptable television transmission should be required. Because of geographic limitations, however, it may be both desirable and necessary to transmit at ranges greater than those indicated by the 5° limitation. An immediately apparent expedient is to consider the use of some portion of the additional range potentially available by transmitting and receiving when the satellite is at an angular elevation of less than 5°. Figure 22 shows maximum radio ranges as functions of altitude at angular elevations of 0°, 2°, and 5°.

[31] Reliable transmission of radio waves several centimeters long can be expected at a 5°-elevation angle; at angles of 1° or 2°, some dispersion will be prevalent.(10) The principal effect will be loss in resolution, but even this may be desirable in place of no picture at all.

The Tracking System

It is evident that if power requirements are considered, it is necessary for the television transmitter to have a directional antenna which can be oriented toward the receiving station. On the basis of orbital computations, a receiving station will know the approximate location of the satellite at any given time.

A station with an appropriately sized receiving antenna will be able to track a 350-mi-altitude satellite for about 3000 mi. The vehicle traverses the distance in approximately 11 min at an average angular tracking rate of 15°/min (the rate is faster at the zenith, being of the order of 34°/min, or 0.6°/sec), this implies that the tracking system must be carefully keyed in with the satellite's system and, further (within the limits of reasonable satellite power consumption), that the ground station's antenna should be as small as possible. The diameters of the satellite's antenna and of the ground station's receiving antenna are assumed to be 1 ft and 16 ft, respectively. Thus the size of the ground station's antenna would be small enough to be amenable to reasonable engineering in mounting, etc.

It is proposed that, for reasons of stability as well as of reliability, the satellite's television camera and transmitter system be turned on, warmed up, and adjusted at the start of the flight, and that it be left on continuously thereafter. The satellite will therefore always be ready to televise on demand of the appropriate ground station.

Of the many possible methods by which antenna-tracking could be accomplished, the optimum would be that which minimizes the complexity, weight, and power requirements of the space-borne equipment. On this basis, the most attractive system yet considered is one in which a tracking receiver in the satellite operates on the continuous-wave signal of a ground beacon to direct the satellite antenna toward the ground station, and—once the space-borne tracking is accomplished—the ground station's receiving antenna is directed to follow the satellite by means of an auxiliary tracking receiver operating on the television signal. The space-borne tracker would operate on a microwave frequency different from and considerably lower than that used for television transmission, but would work through the satellites's television transmitting antenna. The ground beacon would work into a directional antenna separate from that used for television reception, but would be slaved to the latter so as to follow the satellite when the ground tracker takes over. The general nature of the operations of the tracking system is described in the following paragraphs.

The 1-ft-diameter satellite antenna is mounted in gimbals in such a manner that it is free to rotate about a vertical axis and so that the antenna axis can assume any angle with the downward vertical up to a maximum of about 60° (the direction of a ray from the satellite in a 350-mi orbit to a ground station at which it subtends to a minimum angle of 11°; see Fig. 23). The dish-shaped antenna is provided with two feeds: one is fixed on the axis for television transmission at about 10,000 Mc; and the other [32] is offset from the axis and rotates about the axis so that a conical scan is provided for the tracking receiver at some suitable lower frequency, say 3000 Mc. In the search phase, the axis of the dish is maintained at 60° from the downward vertical, the antenna assembly rotates about the vertical axis at a rate of the order of 3 rps, and the nutating feed simultaneously executes a conical scan at a rate of the order of 30 rps. When the ground station appears above the horizon with respect to the satellite, the signals from the ground station's beacon will be received by the conically scanning tracking receiver, which will then operate to disengage the slow search rotation and to maintain the antenna axis in the direction of the beacon, using the conventional servo technique. When the satellite reaches the opposite side of its transit with respect to the ground station, the ground beacon shuts off and the tracker ceases to operate. The satellite's antenna is then rotated about its axis once at the same angle with the vertical as was used in transmitting to the last receiving station. If the next station tracker is not engaged, then the antenna is returned to the primary angle of 60° by stages (probably two revolutions).

This procedure is illustrated in Fig. 24. In the extreme case (provided the next station is not over the horizon), a loss of less than 1 sec in reception may be anticipated. Usually this interval will be about 1/6 sec and will not cause difficulty in continuity of picture-area coverage since successive disengagements from one station to the next (on alternate days, for example) can be made at different points in the orbit. The 3000-Mc tracking frequency was chosen, since an included angle ($\Delta\phi$) of 27 1/2° will illuminate the satellite from a wide range of succeeding ground stations.

Because of the high, and continuously varying, radial velocity of the satellite with respect to the ground station, the 3000-Mc signal of the ground beacon may suffer a Doppler shift of as much as ± 150 kc when it is received at the satellite. The satellite's tracking receiver must therefore have an effective bandwidth in excess of 300 kc if the complexities of automatic-frequency search-and-control circuitry are to be avoided. This wide bandwidth implies that a directional beacon antenna of rather high gain [33] will be necessary if the beacon output power is to be reasonable. Fortunately, it is expected that the establishment of the orbit of the satellite can be made sufficiently precise so that the azimuth angle at which the satellite will appear above the horizon with respect to a given ground station, on a given orbital revolution, may be predicted to within one or two degrees. Hence a beacon antenna having a power gain of about 1000 will yield a broad enough beam to illuminate the satellite when it appears above the horizon.

The design of the ground station's tracker is virtually unrestricted by considerations of circuit complexity and power consumption and could take any of several forms. It could, for example, include a conically scanning tracking receiver similar to that used in the satellite. Such a tracker could use the television transmitter in the satellite as a beacon. The ground station's 16-ft-diameter receiving antenna would have a single feed connected through a power divider to two receivers: one of about 3-Mc bandwidth for television reception and the other of about 400-kc bandwidth for tracking. Both receivers would operate on a television frequency of 10,000 Mc. The feed would be offset from the dish so that a conical scan at a rate of the order of 30 cps would be provided. The search phase would consist in aiming the axis of the dish in the direction of the satellite's scheduled appearance and in oscillating the conically scanning feed back and forth through the axis of the dish in such a manner that the axis of the scan [34] would describe an arc, parallel to and above the horizon, centered on the direction of the satellite. This oscillatory search scan would occur at a rate much slower than the conical scan, say of the order of 3 cps. When the satellite appears, the satellite's tracker first will contact the ground station's beacon, thus aligning the satellite's transmitting antenna with the ground station. The oscillatory search motion of the ground station would then be stopped and, with the axis of the conical scan fixed with respect to the antenna's axis, the entire antenna assembly would be driven by the usual servo system to follow the satellite.

Antenna Gain and Power Required

Appendix II develops the relation of antenna sizes (*d* for the satellite and *D* for the ground station), transmitted power, *P*, transmission wavelength, λ, and all the other factors constraining the signal transmission (signal-to-noise ratio, range, etc.). If these latter factors are considered as constant, K, then the following relation may be stated:

$$P = K \frac{\lambda^2}{d^2D^2} = \frac{125\,\lambda^2}{d^2D^2}, \qquad (1)$$

where *P* is in watts, λ is in centimeters, and *d* and *D* are in feet.

The power supplied to the transmitter, *E*, is not directly proportional to the output power, *P*; although it is desirable to reduce *E* to an absolute minimum, not much can be gained by reducing *P* below 4 watts. Using 4.4 watts for *P* and an assumed wave-length of 3 cm ($v = 10{,}000$ Mc) yields $d^2D^2 = 256$. Choosing $d = 1$ ft yields $D = 16$ ft. These figures are purely arbitrary; they are based on engineering judgment and may be considerably different from those used in the ultimate system. Wavelength, λ, is discussed later.

It is assumed in the above formula that the two antennas are highly directional, with half-power beamwidths of 0.80° and 13° for the ground and the satellite antennas, respectively. Should less directional antennas be employed, considerably greater transmitter power would be required.

Since the antenna beamwidths are small compared with the total of the solid angles over which communication will be required, means must be provided for aligning the axes of the two antennas shortly after the satellite appears above the horizon at a given ground station and for maintaining that alignment as the satellite passes by in its orbit. This has been described previously.

Choice of Transmission Wavelength

While the optimum frequency for television transmission between the satellite and the surface receiving stations will undoubtedly lie in the centimeter wavelength band, its precise value will be determined as a compromise of many factors. One prime consideration, however, is that of minimizing the required power output of the satellite transmitter, which, other things being equal, may be accomplished by maximizing the product of the satellite's transmitting antenna gain and the transmission efficiency of the circuit. A steerable aperture antenna (such as a conventional paraboloid) is required [35] for transmission from a satellite in an oblique orbit, and its gain, for a given aperture area, will be inversely proportional to the square of the transmission wavelength, so that, from this point of view, the frequency should be as high as possible. The transmission efficiency at very high frequencies will be largely determined by atmospheric absorption (water vapor and oxygen) and by losses caused by scattering due to condensed cloud and rain droplets, the total atmospheric losses increasing rapidly with the decrease in wavelength in the high microwave region. (See, for example, Fig. 50, page 109.) The optimum wavelength will depend on the maximum antenna size, on the minimum satellite elevation angle at which transmission is required, and on the least favorable meteorological condition, which is likely to be encountered at the ground station. For example, with a 1-ft-diameter transmitting antenna on the satellite, the optimum frequency for transmission at a minimum elevation angle of 5° to a ground station located in a region in which moderate rain is falling at the rate of 15mm/hr may be shown to be about 15,000 Mc (2-cm wavelength); the optimum wavelength for transmission under the same conditions, but through a tropical downpour, would be about 5000 Mc (6-cm wavelength). Many other considerations enter into the choice of frequency, among which are system losses, ground-receiving, antenna-tracking accuracy, efficiency and reliability of transmitting tubes, etc., the ultimate optimum probably being greater than 5000 Mc and less than 15,000 Mc (10,000 Mc has, of course, been employed in this study).

Transmission of the picture from the satellite to a surface receiving station, as well as the method of presentation or assembly of individual scenes into a meaningful whole, presents problems regarding deterioration of the clarity of the televised picture, which are discussed more fully in subsequent parts of this section. Transmission should be done with a large enough frequency bandwidth so that this part of the over-all system is equivalent to a considerably higher resolution than that component limiting the resolving power, namely, the TV tube.

Enemy Interception and Jamming

Detection and Tracking by Radar. The microwave-radar cross section of the satellite is estimated as averaging less than about 1 m^2. Detection of so small a target in rapid motion and at slant ranges, which vary from a maximum of about 1700 mi on the horizon to a minimum of 350 mi at the zenith, can be shown to be well beyond the capabilities of the most powerful American radars, either now existent, under development, or being proposed.

It is conceivable that the satellite might be detected and tracked by a radar designed expressly for the purpose, one that employs narrow-band techniques at low vhf frequencies at which relatively high average power is available and at which the satellite might behave as a resonant scatterer of a much higher radar cross section. But the frequencies in question (20 to 40 Mc) are subject to severe ionospheric attenuation and refraction effects. The antenna of such a radar would be enormous, with an aperture area measured in thousands of square meters. The difficulties involved in searching for and following a rapidly moving object with such equipment are obvious. Further, [36] even if the system could be made to work, its accuracy and information rate would probably be too low to be useful.

Detection and Tracking by Passive Techniques. The power density of the television signal transmitted from the satellite will be from 10^{-15} to 10^{-18} watts/m^2 at points on the earth's surface illuminated by the main beam of the satellite's transmitting antenna and will be of the order of 10^{-15} to 10^{-18} watts/m^2 at surface points outside the beam.

There is little doubt that an enemy equipped with suitable interceptor receivers *could* detect and track the satellite by means of its television signal and from a site *sufficiently close* to a friendly ground station's receiving station (within about 40 to 200 mi) to be illuminated by the main beam of the satellite's transmitting antenna. The equipment required would be relatively conventional, based on any of a variety of direction-finders and passive radar techniques. The tracking would be in direction only, with crude range information supplied by triangulation from the data obtained at two or more sites. As a primary difficulty would lie in the first acquisition of the satellite's signal, the enemy, unaided by intelligence information, would have to search through a wide band of frequencies and a solid angle of nearly 2π for a source of radiation which would be above the horizon at a given site for a period of only a few minutes per day.

Detection of the satellite's signal by the enemy from sites not illuminated by the main beam from the satellite would be very difficult. While it could be done, so doing would require the use of narrow-band search receivers worked into very large antennas. The probability of making an interception under these conditions would be of the order of 1000 times less than the already low value applied to the more favorable case previously discussed.

Interception of the Satellite's Transmission (Monitoring). Television transmission from satellite to surface would require high-gain tracking antennas at both ends of the circuit. The enemy could receive the message from the satellite only if he had comparable tracking equipment[308] and then only if he managed to acquire the satellite's tracker before

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[308] It would not be necessary for the enemy actually to receive the signal so long as he was able to acquire the satellite's antenna by sending in the 300-Mc tracking signal. However, this type of interception (in effect, jamming) could be overcome by requiring a pulsed tracking signal, similar to an IFF system.

a friendly receiving station did. Successful interception would require that the enemy know almost every detail of the system and its operation.

Interference and Other Countermeasures. The television link can be relatively easily jammed by an enemy who knows the approximate locations of the ground receiving station and the frequency of transmission and who is able to get a jammer within line-of-sight range of a ground station. Even though the ground station's receiving antenna is highly directional (peak gain probably in excess of 20,000) and tracks the satellite, so that the jamming signal will be discriminated against by a factor ranging from a minimum of 1000 (for 30 db peak-side lobes) to an average of more than 20,000, the jammer can take tremendous advantage of the pulse transmission. For example, an air-borne pulse jammer of 10- to 100-kw peak output worked into an antenna [37] of modest gain (100 to 10) carried by an aircraft at 20,000 ft to within -200 mi of the receiving station could prevent reception of a usable picture. Such jammer powers (peak pulse, at a duty cycle of about 1 per cent) and antenna sizes are comparable with, or modest compared with, those of ordinary airborne radars, and spot-frequency jamming is therefore quite feasible.

If the enemy can be denied access to within line-of-sight range of the ground stations, the television system will be relatively invulnerable to interference by the enemy. Counter-measures applied at the satellite-end of the circuit presume possession by the enemy of adequate search and tracking facilities (the difficulties of which were previously discussed) and can be directed only against the satellite's tracking receiver.

Reception and Presentation of the Television Signal

Reception

A description has already been given of the ground station's receiving antenna and tracking system. Consideration is now devoted to the assimilation of the TV pictures after they have arrived at ground level.

Concurrently to read and interpret information on a single television screen at the rate of 10 completely different frames per second is obviously impossible. Furthermore, each ground station receives only a piece of the target system under scrutiny. Thus it appears necessary to record the transmitted data with as little loss in resolution as possible and to forward it to a central evaluation center.

At a first glance, it would seem that a prodigious amount of film would be required to record all the pertinent television frames transmitted. However, analysis reveals that 2.9 hr/day, at most, are spent over USSR and her satellites, China included. At 10 frames/sec, 2.9 hr are equivalent to 1.0 X 10^5 frames/day. It has been shown previously that one satellite will observe a given area only on alternate 35-day periods in daylight. Thus, for the first 35 days' operation, 3.5 X 10^4 frames would be recorded. This is 265,000 ft of 35 mm camera film, or about that used in filming several feature-length movies.

[38] It is believed that during the first 30 to 40 days' operation a fairly comprehensive picture of the USSR would be obtained, and subsequent operations would be concentrated on specific target systems or areas, perhaps with the narrow-scanning-width lens system previously described.

The equipment required at any forward receiving station is not complex. The receiving antenna has already been discussed. An ordinary television receiver will probably suffice for monitoring purposes (to see if the picture quality is satisfactory). Its viewing scope, however, must have a high-persistence screen which will project about one frame out of a hundred.

For recording, a second television receiver is needed. Its scope must be as large as possible and its electric beam spot size must be reduced to a minimum; in short, the whole set must be tailored to the criterion of putting the image on the screen with as little loss in resolution as possible.

The image will then be reduced by camera optics to the appropriate film size; 35 mm may be adequate, but if a significant amount of detail is lost, then 70 mm can be employed. The film does not have to be very "fast," but should be of a fine-grain variety.[309] The camera will be similar to a movie camera but will operate at about one-half the frequency.

Each forward station will be furnished with a time schedule for operating the cameras computed on the basis of the satellite's orbit. Such a schedule will vary from day to day, as mentioned in the discussion on orbits. Some sort of time coding will be included with each frame; a feed-back from the tracking-antenna control will also be fed into this coding, but this is only a crude location device to show up any gross errors in evaluation.

Presentation

The *central evaluation station* will receive the composite films from the forward stations and assemble the story into an integrated whole. Standard photogrammetric techniques call for synchronizing one or more sets of films, together with overlays, etc., [39] to aid in interpretation of results. In such a device, the frames are projected in a mosaic form and compose as the scenes appear on the earth. Also projected could be a master overlay made up of geographical coordinates and, later, after a number of films are taken, of that area of the ground already filmed. The over-all area can be enlarged to any extent necessary for rapid determination of the worth of the films being evaluated. For instance, if a large area is covered by clouds, then just those frames having glimpses of the ground could be separated for subsequent addition to the master mosaic of the USSR.

The cloud pictures would be placed on a larger-scaled photomap so that daily weather maps could be made and preserved.

The entire presentation system should be simple, rapid, reliable, and amenable to standard evaluation techniques.

Summary

To summarize, a 350-mi altitude satellite, having an f/10, 2-in. aperture, 20-in. focal length, Image Orthicon TV camera of 1000 TV lines/in. with a speed of 10 frames/sec, would be capable of resolving scenes of contrast greater than 20 per cent to about 200 ft. Transmitting and receiving antennas for the described system will require careful analysis and design, but their accomplishment does not present any serious research problems. Presentation of the viewed scenes by photographic and photogrammetric methods appears within the limits of known, practiced techniques.

Such a system, employing presently available equipment, is considered satisfactory for both weather and pioneer terrestrial reconnaissance. However, in order to obtain acceptably detailed target evaluation of bomb-damage assessment, the minimum resolvable surface dimension will have to be improved; several possible methods are suggested.

For example, by keeping the frame speed constant but optically reducing the field of view and thereby reducing the scanned bandwidth on the ground, acceptable values for most terrestrial reconnaissance can be attained with present television tubes. This results in not having a daily coverage of the entire target area.

Other means of improvement of the resolvable surface dimensions are an increase in the inherent tube resolution (an increase of about 50 per cent is visualized at this time) and an increase in the frame frequency to 30/sec (about 45 per cent improvement of resolvable surface dimension).

The estimated over-all power, weight, and space requirements of the electronic transmitting system are 350 watts, 300 lb, and 2.25 ft^3, respectively....

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309. Such expedients as, for example, using blue sensitive film with a blue cathode-ray screen can be used to bring out certain details in the viewed scene.