NRO HISTORY

Missile Defense Alarm:

The Genesis of Space-Based Infrared Early Warning

R. Cargill Hall

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Preface

Written over ten years ago, this history of the Missile Defense Alarm System, or MIDAS as the program generally was known, remained classified and for the most part confined to a file drawer. After a security and policy review, late in 1998 Lt Gen Eugene L. Tattini, Commander of the Air Force Space and Missile Systems Center, declassified MIDAS, an action that liberated its history to be shared with a much wider audience. This history compasses the origin and early years of space-based infrared (IR) sensors employed to detect the launch of ballistic missiles and, in time, the flash of ordnance detonated on Earth and in the atmosphere. It addresses the people, institutions, ideas, and machines brought to the task and their relationship to each other over a twelve-year period at the height of the Cold War, between 1955 and 1967. Beside treating the primary actions and events, it also attempts to account for the expectations and tensions that existed among the key participants: aerospace engineers who created the spacecraft and payload, their military superiors who anxiously sought an operational system, and still others in the Pentagon and Congress who doubted whether the technology would work, insisted on more research to demonstrate it, or sought to cancel the program after six ignominious flight failures.

Whatever the technical, financial, and bureaucratic impediments, MIDAS did have the advantage of focused performance requirements. That is, to counter the threat of a surprise nuclear attack against the United States, it was conceived and designed primarily to detect the launch of ballistic missiles and immediately relay early warning of them to American military and civilian authorities. As you will see, the performance requirements imposed on the satellites of its operational successor, the Defense Support Program (DSP), expanded to match the extraordinary capability for IR detection that MIDAS had demonstrated. Bespeaking that 1960s success, the operators and users of DSP, among other satellite systems, recently submitted an array of imposing, often conflicting performance requirements for the second generation operational system, presently known as the Space-Based Infrared System, or SBIRS. The performance thus demanded of this planned two-tier IR space system is such that it cannot be designed and built at a reasonable cost without some compromise in requirements among its civil and military "stakeholders"—but that is another history still in the making.

R. Cargill Hall June 1999

In June 1955 Joseph J. Knopow, a 41-year-old electrical engineer in the Operations Analysis Office, Directorate of Operations, Headquarters USAF, joined the Lockheed Aircraft Corporation in Van Nuys, California.* The career move was hardly novel. Engineers of all kinds changed employers frequently in a burgeoning aeronautical industry at that time fashioning turbojet powered intercontinental bombers and transports, and ballistic missiles of equivalent ranges. In this instance, however, the confluence of Knopow's particular interests, the Air Force contract competition for a strategic reconnaissance satellite, and a genuine concern among U.S. leaders over a possible Soviet nuclear surprise attack, would affect directly the evolution of American missile early warning systems.

Missile Defense Alarm: The Early Years

Shortly after arriving in Van Nuys in the summer of 1955, the firm posted Knopow to Palo Alto, California, 400 miles north in the Bay area. There, the newly named Lockheed Missiles and Space Division had just begun work on the company's proposal for what would become known as the WS-117L reconnaissance satellite program. Back at the Pentagon in the early 1950s, Knopow had evaluated the technology of infrared systems for detecting aircraft and submarines. These studies, based largely on German Luftwaffe literature of a World War II nighttime air-to-air infrared detection system called "Kiel IV," prompted the electrical engineer to consider infrared detection in spaceborne applications. The proper lead sulphide detectors, sufficiently cooled and combined with the needed optical telescope, he reasoned, could be employed in a satellite to detect the burning plumes of ballistic rockets ascending through the atmosphere, and even the exhaust of high altitude air-breathing vehicles.[1]

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* Knopow (pronounced nä-po) joined a select group led by Elwood Quesada and Joseph Charyk that formed the nucleus of what would eventually become the Lockheed Missiles & Space Company, headquartered in Sunnyvale, close by Palo Alto, California.

Figure 1. Joseph J. Knopow, c. 1959-60.

Knopow succeeded in convincing his Lockheed superiors of the infrared sensor's technical feasibility. The concept was adopted, identified as the "satellite infrared detection and surveillance system," and incorporated as "Subsystem G" in the firm's reconnaissance satellite proposal submitted to the Air Force in March 1956. In this application, the Lockheed satellite was to be stabilized on three axes and positioned in space nose downward, much resembling a pencil with its sharpened end pointed at the center of the Earth. The payload would consist of a wide-field infrared telescope mounted on a ring at the forward end of the satellite. The ring, or spin table, would rotate 360 degrees about the vertical axis, scanning an annular area beneath the vehicle, extending at the outer circumference to three degrees above the Earth's horizon, with the inner circumference defined by the limits of the field of view of the telescope. The telescope optical system would focus on a number of lead sulphide detectors. These detectors would convert any infrared signals to electrical impulses which, after amplification, filtering, and processing, could be transmitted back to the Earth.[2]

In June 1956 the Air Force selected Lockheed as prime contractor for the WS-117L reconnaissance satellite and awarded a contract to the firm for its development in October. Subsystem G, the space-based infrared detection and surveillance system, at that time bordered on science fiction. But it was nonetheless judged a promising application and doubtless contributed to the firm's selection. Now appointed subsystem manager, Knopow set to work in earnest to see that application realized. He subcontracted with the Aerojet Engineering Corporation for feasibility studies and then a Series I infrared detector payload devoted exclusively to ICBM detection,* and with Baird-Atomic, Incorporated, for an infrared scanner to be used in tests on board balloons and aircraft. The latter effort was crucial, for it had to determine the precise nature of background radiation (radiation emitted from the Earth, atmosphere, and clouds) that would be encountered by the infrared detectors viewing the Earth from a satellite.[3]

However promising the Lockheed satellite infrared detection and surveillance system might appear in theory during the mid-to-late 1950s, many experts seriously questioned its technical feasibility. Natural background radiation, they argued, could not be distinguished from a target missile. It might also trigger "false alarms" in the satellite payload when sunlight reflected from clouds illuminated the detectors, for example, instead of the infrared energy radiated by a rocket engine's exhaust during powered ascent. Enough false alarms and a real missile attack might be discounted. More to the point, respected engineers then designing infrared systems for ground applications worked with four to seven lead sulphide detectors; coupling 10 of them was considered the outer limit of the art. The audacious gentlemen at Lockheed and Aerojet proposed coupling 27 detectors in *Earth orbit* and, using filters, scanning different parts of the spectrum![4]

Officials of the Advanced Research Projects Agency (ARPA), Ralph Zirkind in particular, numbered among those with the gravest of doubts. Created in early 1958, ARPA briefly controlled all military satellite programs until September 1959, and Knopow found himself increasingly called

*Though theoretically feasible, given the state of the art in 1956-57, detection of high altitude air-breathing vehicles was judged too ambitious a step to attempt. At Lockheed, Subsystem G soon became known informally as the "ICBM Attack Alarm System."

upon to explain program details and infrared theory to government visitors in California and on trips he made to Washington. Since ARPA controlled the Subsystem G budget instead of the Air Force, he had no alternative but to comply. By mid-1958 aerial test flights had measured background radiation, and Lockheed settled on operating in the 2.7- and 4.3-micron regions of the spectrum. These regions were usually avoided for infrared scanning in Earth-bound applications because of water vapor absorption. Lockheed planned to operate Earth-orbiting infrared payloads in the very same narrow parts of the spectrum to take advantage of the filtering effect that water vapor provided against background radiation. Still, the doubters persisted. Years later Knopow recalled:

> We made measurements from balloons. We made measurements from airplanes. We made measurements from the U-2. We made measurements of all kinds, and analyses, and were usually successful when we gave a briefing to [officials] from Washington. They agreed that by using the spectral characteristics and the spatial characteristics of the background elements such as clouds and water, we could detect an ICBM in the presence of clouds. But when they went back home . . . they would . . . see all those bright clouds, . . . and by the time they arrived in Washington, after 2,500 miles of looking at that stuff, they got unconvinced and we had to go back to Washington and convince them again. And then we left them and by the time they came back to see us again it was a very difficult job getting them to believe that you could really see a missile launch in the presence of cloud backgrounds.[5]

The doubting Thomas' notwithstanding, by mid-1958 Knopow had convinced a majority of WS-117L program officials of the theoretical feasibility of the ICBM attack alarm system, and begun the fabrication of experimental payloads. Bespeaking these achievements, on 17 September the Air Force Ballistic Missile Division in Inglewood recommended accelerating the effort, and on 15 November 1958 ARPA issued Order No. 38-59. That order separated the infrared detection and surveillance system from the basic WS-117L (SAMOS) program and established it as an independent satellite program identified as the Missile Defense Alarm System (MIDAS). The formal recognition brought to Knopow the title Program Manager and a deputy: John C. Solvason.

Both men dedicated themselves to MIDAS and for the next few years "lived" for the program; they ate, drank, slept, dreamt, and thought about it 24-hours a day. The MIDAS staff at Lockheed, meanwhile, had increased in size from one person in mid-1956 to about 50 engineers and administrative support personnel at the close of 1958. While Knopow divided his efforts between "convincing" the skeptics and attending to the Agena satellites and infrared payloads scheduled for demonstration test flights in late 1959, other members of the staff devoted themselves to preparing "Program Development Plans" for an operational MIDAS requested by the Air Force.[6]

If some officials at ARPA and others in the office of the Director of Defense Research and Engineering (DDR&E) needed to be persuaded that MIDAS would work, by 1959 the enthusiasm for MIDAS of many Air Force officials needed to be restrained. Contemporary Soviet space triumphs and erroneous intelligence estimates that posited a "missile gap" in favor of the Russians had heightened fears of an ICBM surprise attack on the United States. On 9 February 1959 Headquarters USAF issued an amendment to General Operational Requirement 80 that called for a date of "operational availability" for MIDAS "not later than CY 1962." On 12 February Air Force Under Secretary Malcomb A. MacIntyre wrote Secretary of Defense Neil H. McElroy affirming that the service judged MIDAS to be a program of the highest priority, that its development was most urgent, and he requested additional funds to accelerate the effort. Key members of the U.S.-Canadian North American Air Defense Command (NORAD) and the Continental Air Defense Command (CONAD) also argued that MIDAS should be pressed into operational service at the earliest opportunity. Among them, Brigadier General Arthur J. Pierce, Director of NORAD Plans and Requirements, in a letter to the Joint Chiefs of Staff, asserted that the ballistic missile early warning radar system (BMEWS) then abuilding in the far north would furnish insufficient advance notice. Under optimum conditions it could provide the nation 15-minutes warning of an ICBM attack. The Lockheed-Aerojet space-based system, he averred, would double the warning time to 30 minutes.[7]

An additional 15 minutes warning appealed mightily to key members of General Thomas Power's staff at the Strategic Air Command (SAC). More SAC bombers could be scrambled into the air, and the number of bombers maintained on airborne alert could be reduced. They, too, lent their support, and SAC came down hard in favor of an operational MIDAS. Underscoring this widespread support, on 18 September 1959 Secretary of Defense McElroy reorganized the military space program, removed ARPA from its direction, and assigned to the Air Force responsibility for MIDAS. Though the Lockheed program office could take heart in the organizational change and a growing Air Force advocacy, it translated ultimately into increased requests from the Ballistic Missile Division in Inglewood for program development plans of an operational MIDAS. And Knopow, still finding it difficult to sell the technical feasibility of a spaceborne-infrared detector in other quarters, had yet to demonstrate it in an actual test flight.[8]

Between 1958 and 1964 the Lockheed program office issued a number of program development plans, each responding to changes in Air Force requirements or direction. Because the actual performance of the infrared detectors in space remained in question, early plans proposed operating in low-Earth orbits.* The plans specified multiple satellite configurations, usually 8-to-20 vehicles in controlled polar (later, simplified random polar) orbits at an altitude of 1,000 nautical miles (nm), a distance increased to 2,000 nm in later plans. Early versions called for four test evaluation flights in Phase I, six research and development flights in phase II, and optimistically

*Increasing the altitude would decrease the number of satellites required to cover all of the Sino-Soviet Block; however, the strength of the infrared signal also decreased inversely with the square of the range, making it more difficult to detect the target and achieve the desired resolution.

projected an operational system in the early 1960s in Phase III.[9] At the beginning of 1960, however, the first two MIDAS test and evaluation satellites were just being readied for launch at Cape Canaveral, Florida.

Trial and Tribulation

Although ARPA officials had briefly considered launching MIDAS satellites atop a Thor booster, the weight of the Agena A liquid-propellant upper-stage booster-satellite and its Aerojet infrared payload precluded that option. A modified Atlas ICBM would comprise the first stage and, indeed, it was employed on all Lockheed MIDAS flights in the 1960s.

At Aerojet, Marvin D. Boatright and Alfred H. Gale served as Knopow and Solvason's counterparts, and worked closely with William A. Hubbard, a physicist in the firm who conducted the payload system calculations throughout the early MIDAS era. The Aerojet payload built for the first two low-altitude test demonstration flights* consisted of a Bouwers-concentric telescope and 27 lead sulphide detectors. Mounted in a fork beneath the spin table, the telescope elevation could be adjusted on command. The spin table would rotate 360 degrees at two rpm about the vertical axis of the satellite in a nose-down attitude. A comparable spin table would also be used on all Lockheed MIDAS flights.[10]

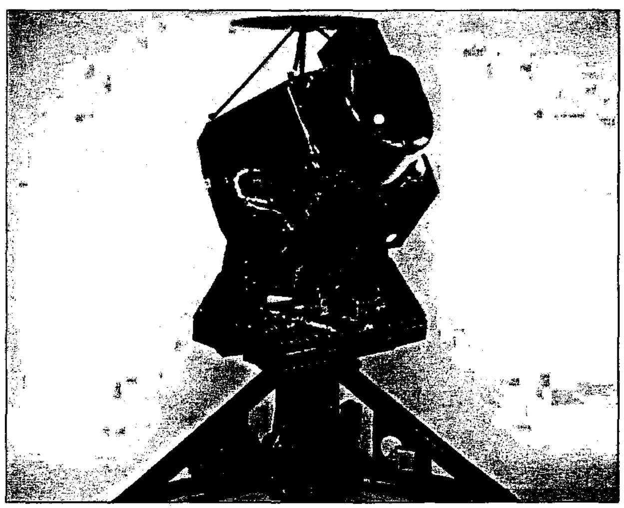

Figure 2. MIDAS Series I Infrared Sensor Payload.

These initial test flights were to be launched into low altitude, near-equatorial orbits from Cape Canaveral, Florida. At the Cape in February 1960, Joe Knopow oversaw the final checkout of the first MIDAS

* Programmed for low inclination orbits at 260-nm altitude.

spacecraft and payload. On 26 February he watched the Atlas booster engines ignite and lift the ensemble skyward until the engine flames could hardly be seen. But improper separation of the Agena second stage caused it to collide with the first stage Atlas, and the debris rained into the South Atlantic Ocean.

That evening the *Orlando Herald* headlined: "Spy in the Sky, Asleep in the Deep." Knopow never forgot it. Three months later, on 26 May 1960, the second and last of the Series I MIDAS test flights rode successfully into a low inclination 260 nm orbit atop another Atlas, but the satellite tumbled as it circled the Earth and, after the first dozen orbits, the Agena communication link failed. The payload could not be operated as planned.[11] No Test.* At least that was the polite term engineers liked to use in these

Figure 3. On a tour of Cape Canaveral, President Dwight D. Eisenhower, accompanied by Secretary of Defense Thomas Gates, Maj General Donald Yates (at Eisenhower's left), and others, visited MIDAS 1 on 10 February 1960 as the vehicle was being prepared for launch.

*The Aerojet payload did operate well even though tumbling, and it observed backgrounds and the infrared energy of a star, presumed to be Betelgeuse.

situations. Whatever it might be called, MIDAS remained undemonstrated for missile warning, and new voices in the Defense Department began to question the reliability of the MIDAS satellite as well as the feasibility of its infrared applications. In the Lockheed program office, Joe Knopow felt the pressure.[12]

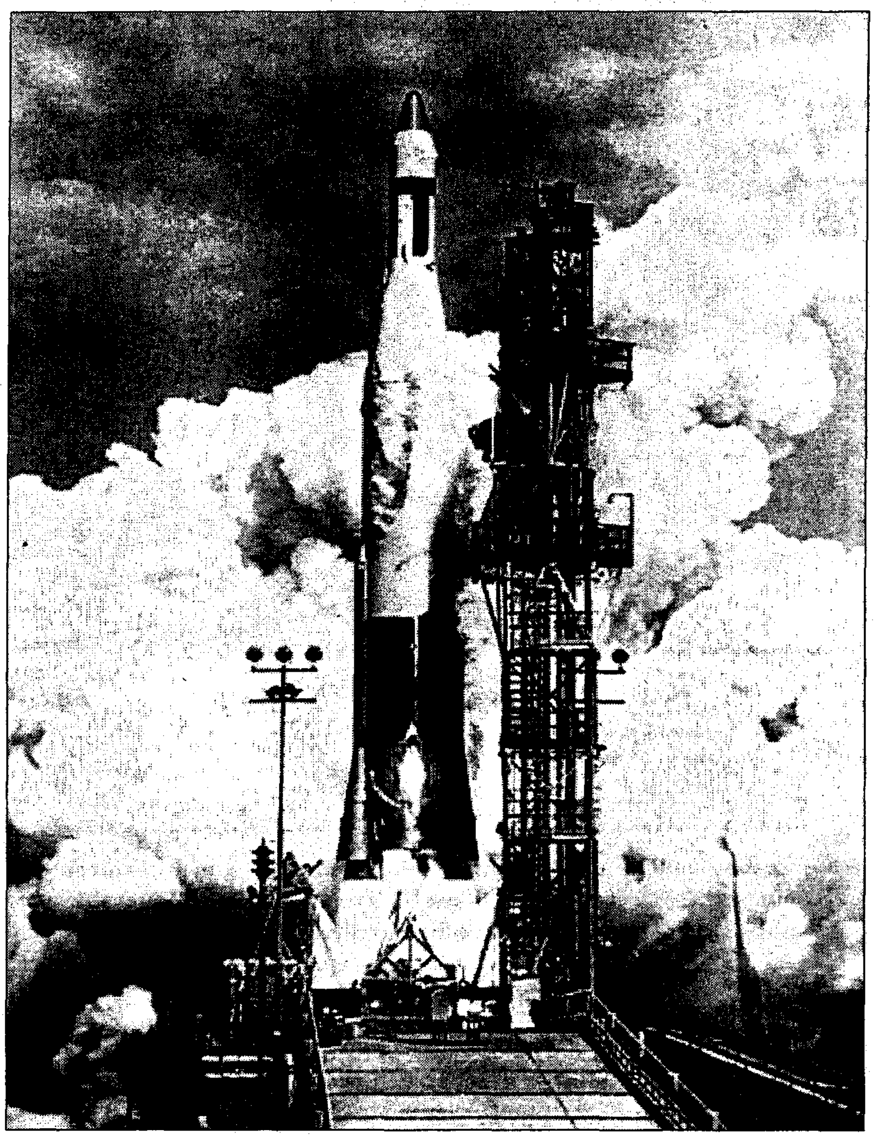

Figure 4. MIDAS 1 lifting from Launch Complex 14, Cape Canaveral, on 26 February 1960.

The program had proceeded thus far in part because panels of independent scientists had verified the Lockheed and Aerojet analyses of the space-based infrared applications. An ARPA board* back in February 1959 judged missile detection and alarm to be a straightforward method "based on a few physical laws and one that cannot readily be circumvented." Though more information was needed "on background characteristics and the technical complexities of necessary

*Composed of Carl Overhage, MIT; Sidney Passman, The RAND Corporation; Edward M. Purcell, Harvard University; and Chalmers W. Sherwin, University of Illinois.

discrimination devices," the members urged "most strongly that development and test flights of this missile detection system be pursued with top priority." Shortly after the flight of MIDAS 2, between 6-9 September 1960, 12 members of the President's Scientific Advisory Committee, led by W. K. H. Panofsky of Stanford University, also evaluated MIDAS.* This panel likewise found the concept to be sound. Though acknowledging major technical difficulties had yet to be overcome, panel members recommended vigorous efforts to achieve an operational system in 1963.[14]

Despite the scientific approbation, Defense Department leaders maintained the funding restrictions imposed on MIDAS earlier in 1960 and refused to approve an operational system. The MIDAS Program Director at the Air Force Ballistic Missiles Division in Inglewood, Lt Col Quentin A. ("Q") Riepe, advised Lockheed in August that this state of affairs bespoke "a lack of confidence that the current R&D program can provide a reliable and effective [operational] system." Accordingly, he redirected the program. It would now proceed toward development and system test flights. Emphasis would be placed on

Figure 5. The first Air Force MIDAS Program Director, Col Quentin ("Q") Riepe (1959-1961).

*The panel members included physicists Harold Brown, Director of the Lawrence Livermore National Laboratory, Sidney Drell, Stanford University, and Jerome Weisner of MIT.

ensuring the reliability of all system components.[15] Underscoring Riepe's redirection, at the Pentagon the Director of Defense Research and Engineering, Herbert York, approved the launch of two radiometric payloads to measure more completely the Earth's background radiation. Launched aboard Discoverer 19 and Discoverer 21 Agena satellites on 20 December 1960 and 18 February 1961, respectively, these devices transmitted data for one-to-two days and validated previous projections.[16] All of the available scientific evidence seemed to confirm the technical feasibility of the MIDAS concept. In 1961 one question remained unanswered: could Lockheed and the Air Force make it work?

At the Lockheed program office in Sunnyvale, California, Knopow and his colleagues recast MIDAS activity to meet the direction of Col Riepe. Succeeding MIDAS flights were divided among developmental ones in Series II and Series III, and prototype flights in Series IV, with each series consisting of three or four flight vehicles.[17] In the Air Force major commands and Air Staff offices, however, enthusiasm for an operational MIDAS was undiminished. If, as projected, MIDAS could increase the warning of a missile attack from 15-to-30 minutes, it would be a vital asset to the service and the nation. On 16 January 1961, Secretary of Defense Thomas S. Gates, Jr., about to leave office with the Eisenhower Administration, approved an Air Force request to assign "operational responsibility" for MIDAS. A few weeks later, on 13 February, Headquarters USAF assigned that responsibility to the Air Defense Command (ADC) and designated it to represent the service in all dealings with NORAD. Acting quickly, on 15 March ADC submitted another development plan for an operational MIDAS to Under Secretary of the Air Force Joseph Charyk. Charyk, who knew well the technical complexity of military spacecraft and of their operation in space, disapproved. The service, he counseled Air Force Chief of Staff Curtis E. LeMay, had first to demonstrate conclusively the MIDAS early warning techniques. On 22 June 1961, a few weeks before the launch of MIDAS 3, LeMay, agreed.[18]

In late June and early July 1961 final preparations for the launch of MIDAS 3, the first of three test vehicles in Series II to be launched into polar orbit, took place at the Point Arguello Launch Complex, Vandenberg AFB, California. MIDAS 3 consisted of an Agena B, a larger, new model booster-satellite. Five feet in diameter and 30 feet long, it was nearly twice the length of its Agena A predecessor. The increased tankage and a new "dual-burn" rocket engine would permit reaching a planned circular polar orbit at an altitude of 2,000 nm, the orbit then considered most appropriate for an operational constellation of MIDAS satellites. Power was to be furnished by two solar arrays fixed to the aft equipment rack so as to maximize sunlight intercept, coupled to storage batteries, instead of the batteries alone used on the first two missions.

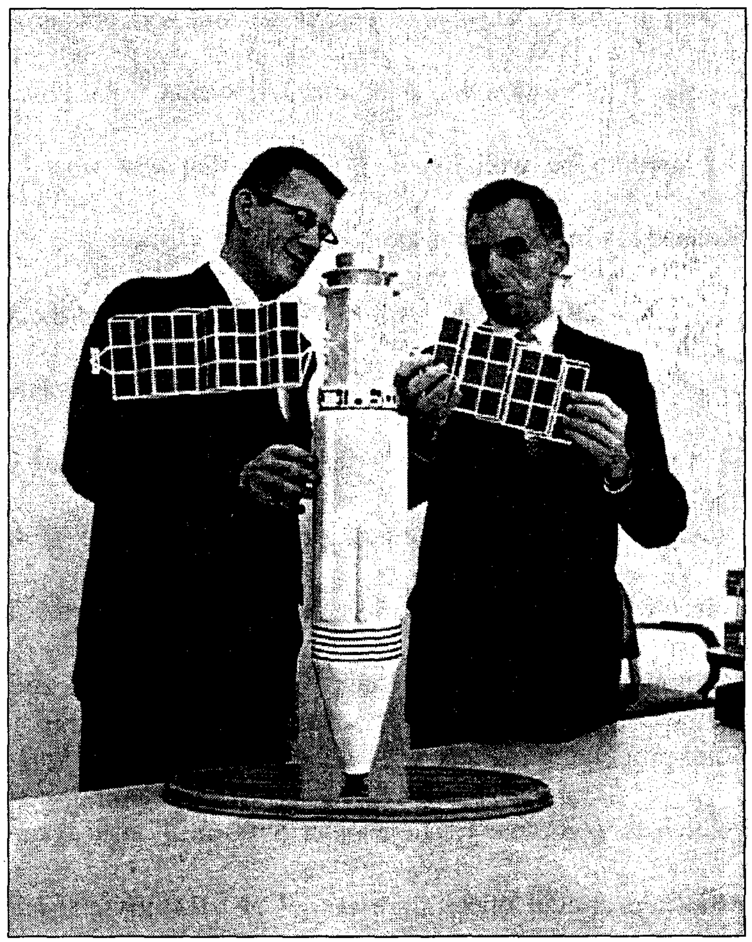

Figure 6. Joe Knopow, at right, examines a model of a MIDAS Agena B Series II Satellite with John Solvason, c. 1960.

This vehicle and its Series II companions carried a new infrared payload built by Baird-Atomic, one that featured 175 detectors capable of sensing ICBM targets at a maximum slant range of 4200 nm. The payload was designed to scan at a rate of six rpm, a rate of rotation three times faster than the

Series I payloads. Every 10-seconds the detectors would view approximately 25 million square nautical miles of the Earth's surface, allowing as many as nine possible "looks" at an ICBM between the time it reached 35,000 feet and missile burnout. That number of looks was believed sufficient to identify the direction of missile travel.[19]

On 12 July 1961 the Atlas booster carrying MIDAS 3 roared to life at Vandenberg AFB. The booster ensemble rose slowly and disappeared from view. Air Force and Lockheed program officials who followed its progress rejoiced on word that the Agena successfully reached a 2,000 nm circular polar orbit. An hour later they despaired. One of the two solar arrays had failed to deploy properly. Only limited payload data was obtained before a power failure occurred in the Agena. The mission was over after five orbits.[20] Air Force Under Secretary Charyk's reservations appeared to be well founded. At least that was what Defense Department leaders in the new Kennedy Administration soon concluded.

On 29 July 1961, while MIDAS officials on the West Coast sought to determine exactly what went wrong with MIDAS 3, the newly appointed Director of Defense Research and Engineering, Harold Brown, briefed Secretary of Defense Robert S. McNamara on the status of the program. Formidable technical problems remained, Brown declared, though he thought them solvable in time. The MIDAS satellite system would provide only 5-to-20 minutes advance warning of an attack by liquid-propellant ICBMs, he believed, and its ability to detect land and sea-based solid-propellant rockets was at best, questionable. Program costs were also formidable: $500 million to complete R&D, another $500 million to complete an operational system, and Brown estimated annual operating expenses at $100-to-$200 million. Was an extra 5-to-20 minutes of warning worth the needed expense and effort? Brown advised McNamara that he would form a special task force to evaluate the program in general, and this question in particular.[21]

The group formed for this purpose began its evaluation in late September 1961. Chaired by Jack P. Ruina, Director of ARPA, and composed of experts drawn from within and outside the government,* during the next two months its members visited MIDAS contractor and government facilities around the country. Meanwhile, in southern California, on 21 October the Air Force launched MIDAS 4. An Atlas roll-control failure shortly after launch propelled the Agena into an improper ascent trajectory. After separating from the Atlas, the Agena used an abnormal amount of attitude control gas during first and second burns as onboard systems sought to compensate for the trajectory dispersion. Once in orbit, the Agena's attitude continued to fluctuate and all control gas was exhausted by the time it completed its first revolution of the Earth. One of two solar arrays aboard the tumbling Agena failed during the fourth orbit, power depleted, and all electrical equipment was shut down after the 56th orbit.[22] The "Ruina Group," as the Brown investigatory panel came to be called, unquestionably had much to consider.

The Ruina Group completed its deliberations and submitted its report, *Evaluation of the MIDAS R&D Program*, to Harold Brown on 30 November 1961. Members of the group concluded that MIDAS probably was worth the effort, but that effort needed a new direction. Members believed that the infrared system probably could detect large liquid-propellant ICBMs that emitted a high radiance, though they also agreed with Brown that it probably would be unable to detect solid-propellant rockets with depressed infrared signatures, such as Minuteman and Polaris. Moreover, Ralph Zirkind, ARPA's infrared specialist, speculated that the number of false target alarms generated by the infrared payload could be as great as 1-10 per six-second scan for a liquid-

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*Beside Ruina, the members were Benjamin Alexander, Defense Research Corp.; Robert S. Sargent, ODDR&E; Dean Gillette, Bell Telephone Laboratories; M. A. Ruderman, UC Berkeley; Montgomery Johnson, Ford Aeronutronics; Hector R. Skifter, Airborne Instrument Laboratory; Lt Col G. T. Grottle, USAF; and Knopow's old nemesis, Ralph Zirkind of ARPA.

propellant ICBM, and an incredible 2000-4000 per scan for a solid-propellant Polaris-size missile—if it were detectable. The complexity of the existing MIDAS spacecraft, the board continued, militated against a reliable operational system, and Air Force attention, riveted on achieving an early operational capability, had contributed to neglect of the research and development effort needed to attain it. The group therefore recommended that the program be redirected toward a simplified research and infrared measurement effort. No further consideration of an operational system should be entertained, the group advised, until Lockheed and the Air Force demonstrated the technical feasibility of infrared missile detection and alarm.[23]

On 8 December 1961, Harold Brown sent the Ruina report to Secretary of the Air Force Eugene Zuckert. In his cover letter, Brown told the Secretary that he agreed with the report's conclusions and recommendations, and he expected the Air Force to act on them.[24] At that time, the service and Lockheed also had not achieved a success in the reconnaissance satellite program known as SAMOS. The report's implications of mismanagement and misdirected effort thus proved doubly serious. Air Force directives that complied with Brown's wishes soon moved down through the chain of command.[25] The first opportunity to belie at least the report's conclusions came in April 1962, with the launch of MIDAS 5.

MIDAS 5, the third and last of the Series II flights carrying a Baird-Atomic infrared payload, lifted from Vandenberg AFB on 9 April 1962. The spacecraft achieve its planned polar orbit, stabilized properly, and the solar arrays extended and began generating the needed electrical power. Turned on, the infrared payload checked-out during the first few orbits of the Earth.* While

*This Baird payload employed a faceted outer optical element. The flight test returns later showed that each of the facet boundaries reflected sunlight, which inundated the system with noise, a crucial design flaw; whether it would have detected missile launches in the presence of high level noise remained open to question.

Air Force personnel readied target missiles for launch when in view of the satellite, the hopes and aspirations of program officials soared. During the sixth orbit a massive electrical power failure occurred aboard MIDAS 5, and all control over the vehicle was lost.[26] Once again the mission ended prematurely—and the worst of the Ruina report implications seemed confirmed: the MIDAS program, if not the concept, was a resounding failure.

Shortly after returning to Sunnyvale from the southern California launch site, Joe Knopow was rushed to the hospital where he underwent surgery for hemorrhaging ulcers. As often happens during the introduction of a new technical innovation, the innovator lights the fire, but others are called on to tend the hearth and fan the flames. So it was in this instance. The Lockheed Missiles & Space Company reassigned Knopow as Director of its Electronics Division. His deputy, John Solvason, picked up the reigns as MIDAS program manager.[27]

Solvason had his hands full. The new Lockheed manager on the west coast would supervise the MIDAS program as a research and development effort,* deal with a new investigating committee established by the Air Force in response to the Ruina report, and attend to the fabrication and test of the remaining Series III MIDAS satellites. (In the wake of the Ruina report, the Defense Department cancelled Series IV flights and substituted additional radiometric missions in their place to conduct further measurements of the Earth's background radiation.) In Washington D.C., meanwhile, other officials sought to strictly compass Air Force efforts on a redirected program.

Knowing that Air Force leaders continued to favor an operational MIDAS in spite of the Ruina report, the Director of Defense Research and Engineering, Harold Brown, on 25 June 1962

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*Heavy emphasis would be placed on systems analysis, systems development, and further radiometric measurements of the Earth's background radiation. The Air Force, nevertheless, still called on the Lockheed program office to produce yet another program development plan for a simplified operational MIDAS comprised of random polar orbits. (See R. Cargill Hall, *Program 461 Historical Monograph,* p. 2-47.)

wrote to the Assistant Secretary of the Air Force for Research and Development, Brockway McMillan. "As I have previously pointed out," Brown observed, "the MIDAS system should not be oriented toward an operational system at this time." Instead, it should remain "an R&D program oriented toward developing the techniques necessary to resolve the remaining basic issues and must not [be directed] toward a specific operational date." Continued Air Force attempts to press MIDAS toward an operational system, he concluded, "would make it almost impossible to solve the design and test problems which have so far resulted in the acquisition of very little in-flight data. By inhibiting the design of new payloads, it would also be likely to present us with a 'system' which generally did not work, and, when it did, could see only the few missiles of high radiance." The Series III Aerojet-General payload design, Brown strongly implied, could not be relied upon. Shortly thereafter, on 12 July, McMillan emphatically reminded Air Force Chief of Staff and former SAC Commander, General Curtis LeMay, that MIDAS R&D program objectives consisted of background radiometry measurements, target radiometry measurements, and "feasibility demonstration of sensor detection at 300/kw/STR and 100/kw/STR radiance levels, and possibly at 30/kw/STR . . . ."[28]

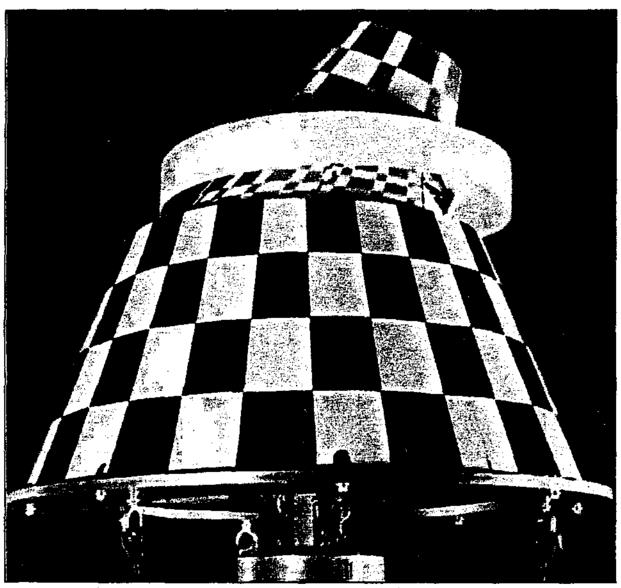

Figure 7. MIDAS Series III Infrared Sensor Payload on its spin table attachment.

Except for engineering changes intended to improve spacecraft reliability, the four remaining Series III vehicles were essentially identical to those in Series II with one important difference: they carried an improved Aerojet-General infrared payload. It featured a Bouwers concentric telescope with an 8-inch aperture. The detector array

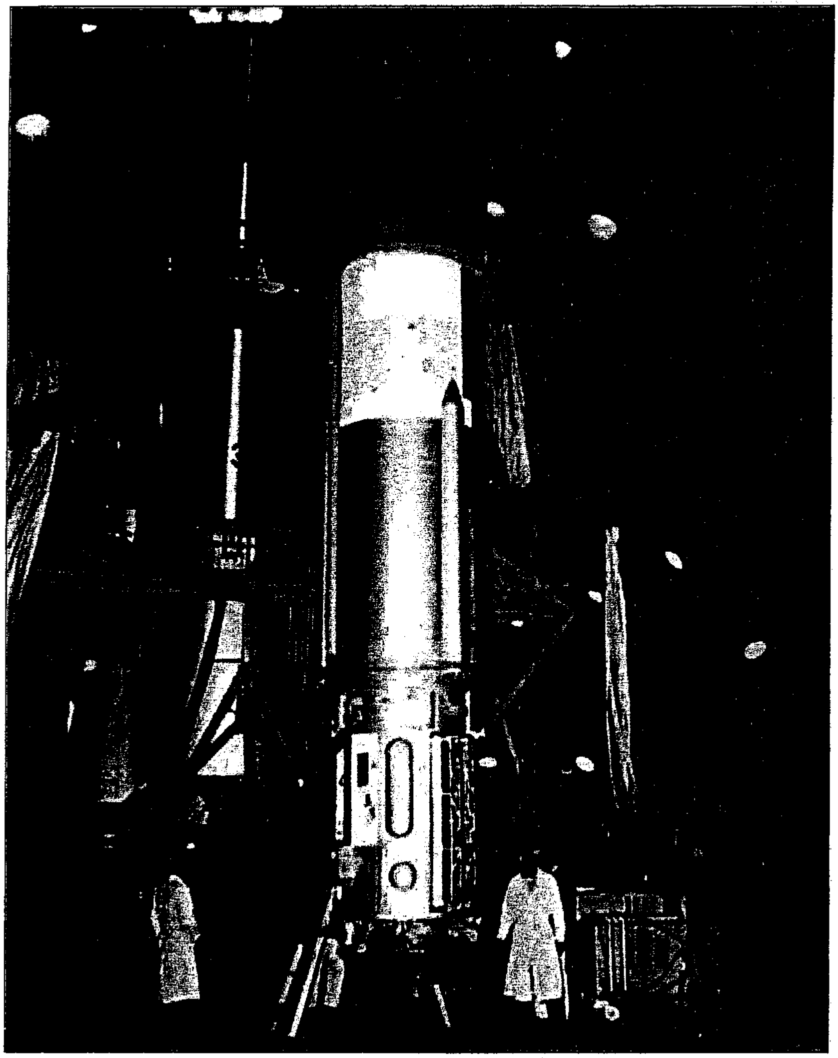

Figure 8. MIDAS 6 Agena B prepared for stacking atop the Atlas booster (in background), at Point Arguello Launch Complex 1-2, VAFB, November

on the surface of the focal-plane assembly contained 184 lead sulphide detectors arranged in eight vertical columns of 23 detectors each, which provided complete vertical coverage of a 24-degree 58-minute field of view. The 2.7-micron system provided both spectral and spatial background rejection, and emphasized boost phase detection of missiles in the "Atlas class." The telescope rotated on its spin table at 6 rpm, like its Baird-Atomic predecessor.[29]

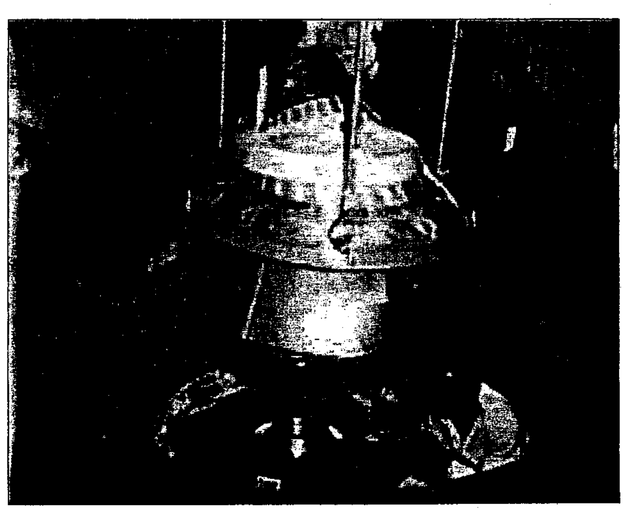

Figure 9. Installation of the MIDAS 6 Series III Infrared Sensor Payload atop the Agena B at PALC 1-2, November 1962 (note the spin table interface).

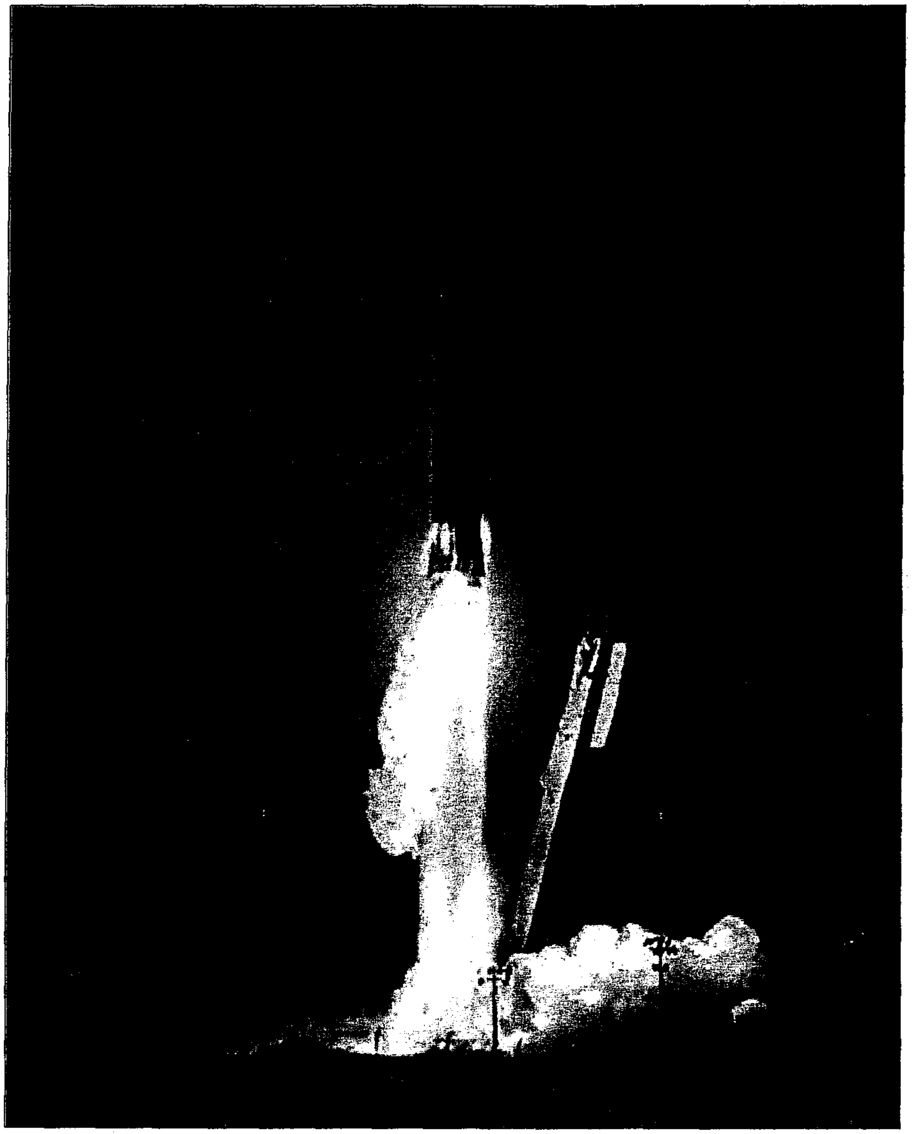

Figure 10. MIDAS 6 lifting from Launch Complex 1-2 at Point Arguello, VAFB, on 17 December 1962. (Mounted on railroad tracks, the launch tower, in which the vehicle was stacked and checked out, has been rolled back, out of view.)

Eight months after taking command of Lockheed's program office, on 19 December 1962, John Solvason watched nervously as MIDAS 6 was launched at Vandenberg AFB. Eighty seconds after liftoff the Atlas veered off course. A range safety officer pressed the destruct button and a shower of debris cascaded Earthward. Another MIDAS found itself "asleep in the deep," this time in the Pacific Ocean.[30] Was there no end to it? That question began to be debated more intensely among American defense leaders in the Pentagon, a debate now joined by angry politicians who were asked to approve funding of the hapless program that had already cost taxpayers some 425 million dollars.

During the first week of May 1963, while final preparations for the launch of MIDAS 7 were underway on the coast of southern California, Harold Brown found himself under heavy fire from both sides of the aisle in Congress. Addressing the subject of missile defense alarm during appropriation hearings in the House of Representatives, Brown announced that the MIDAS program had been partially terminated earlier in the year and reduced to a few remaining test flights and experiments—all intended to explore design problems and background radiation. Should the infrared system prove itself, he concluded, it might again be reconsidered "if a cheap, reliable launch vehicle, and simple satellites of long life, can be designed." But even a research program was too much in the view of Daniel J. Flood, a Democrat from Pennsylvania: "What makes you . . . want to turn this over to the Air Force and say, 'Go and sin no more,' with another [deleted] million? Do you not feel a little perturbed that these people are not qualified or competent or the proper agency to do the program . . . ? What about the Bureau of Animal Husbandry," Flood jibed, "Or something like that?" George H. Mahon, a Texas Democrat, held Lockheed primarily responsible for the sorry state of MIDAS affairs. "To go back to a company that has failed, and to people who have failed to solve the problem, seems to be somewhat questionable," he asserted. The Defense Department, Mahon continued, should consider contracting with other companies for this program. Glenard P. Lipscomb, a California Republican, emphatically agreed: "It is on the record that the company failed." "I think the program is what I said failed," Brown replied tartly.[31]

The Air Force, Lockheed, and Aerojet would be granted the reduced funds for MIDAS in Fiscal Year 1964, but in early May 1963 the stinging indictment—failure—had been securely pinned to their collective backsides. Up and down the chain of command, program participants knew well that another flight failure would result in major changes, changes likely to include sharply altered careers. That knowledge created an environment of palpable tension as preparations

Figure 11. The second Air Force MIDAS Program Director, Col (later Brig Gen)Lewis S. Norman, Jr. (1962-63).

concluded at Vandenberg AFB for the launch of the second Series III spacecraft. John Solvason, Marvin Boatright, and their Air Force counterpart, Colonel Lewis S. Norman, Jr., checked and rechecked every important detail. Then they waited, hoping that the number seven might also portend some luck.

On 9 May 1963 MIDAS 7 ascended from Vandenberg AFB and successfully achieved its planned, circular polar orbit at 2000 nm. Moreover, much to the excitement, relief and pleasure of all concerned, the spacecraft performed all but flawlessly for the next six weeks.* During this period MIDAS 7 detected all of the ballistic missiles launched within its field of view and relayed the data to a control center in Sunnyvale, California. These missiles included not only three liquid propellant Atlas and Titan ICBMs, but off-line tapes also revealed detection of seven lower radiance solid-propellant Minuteman and Polaris missiles. The Aerojet Series III payload achieved an operating radiance level sensitivity, with signal-to-noise, of 50 kw/STR, far better than anything the Ruina Group had supposed possible. MIDAS technology was undeniably demonstrated, payload performance markedly exceeded expectations in the detection of solid-propellant rockets, and,

*At which time it powered down as seasonal changes reduced the sunlight intercepted on its fixed direction solar arrays.

despite the pronouncements of Ralph Zirkind and others, background radiation posed no serious problems—false target alarms were negligible. The Lockheed-Aerojet missile detection satellite was fully vindicated.[32]

MIDAS had succeeded on its seventh flight in 1963—and succeeded beyond the expectations of even its most ardent proponents. Along the way to that success, program participants had contended with a succession of panels and committees that assayed the program's prospects and progress. As opinions changed at the Pentagon, they had been directed to reorient the program first one way and then another. And they had shouldered the public criticism, even excoriation, of Defense Department officials and members of Congress. Unbeknownst to virtually every one of them, they also had bested the record of the CORONA Program by half! CORONA, a covert satellite reconnaissance effort that masqueraded publicly as the DISCOVERER biomedical research program, did not retrieve a film canister from orbit successfully until flight 14.

The last two of the Series III MIDAS flights followed in quick succession. MIDAS 8, launched on 12 June 1963 failed again when the Atlas booster malfunctioned during ascent. MIDAS 9, launched a few weeks later on 18 July, achieved the desired 2000 nm orbit, but one of the two Agena solar arrays did not extend. The infrared payload, nevertheless, operated successfully for 96 orbits and detected one American missile launched within its field of view, as well as Soviet missile launch activity, before a power failure terminated the mission.[33]

In the Defense Department, the unexpected, unqualified success of the satellite Missile Defense Alarm system would rekindle debate and provoke further studies of the program over the next three years. Although three more 2000 nm altitude MIDAS vehicles subsequently would be approved and flown in 1966, the flight of MIDAS 9 rang down the curtain on the original program. American military leaders who evaluated its technical prospects now began to consider orbital operations at much greater altitudes, and additional objectives—objectives that would significantly expand the primary mission of basic missile defense alarm. In mid-1963, along with a core deterrent of long-range bombers, ICBMs, and SLBMs, the Air Force MIDAS appeared likely to become the "fourth leg" of the nation's strategic forces.

An Expanded Mission, A New Name

Between mid-1963 and mid-1966, before a firm choice was made on the next generation of infrared detection and surveillance satellites, American military leaders reevaluated and again changed the direction of the MIDAS program. Harold Brown, Director of Defense Research and Engineering and former skeptic, triggered the first major change on 7 November 1963 when he ordered the Air Force to cancel the radiometric flights he had requested in late 1961. Now he substituted in their place a three-flight MIDAS research test series, once more directed toward the detection of missiles, to become known as Program 461. The Aerojet payload in this series, however, would be designed specifically to detect, in real-time, lower-radiance sea-launched ballistic missiles (SLBMs) and medium-range ballistic missiles (MRBMs), and be capable of determining their launch locations, on two sightings, within a range of 8-to-10 nm. The radiant characteristics of all of the missiles detected around the world also would be identified, measured, and catalogued. Once again the Lockheed spacecraft were to be placed in circular polar orbits at 2000 nm, but now possess a reliability of *six months* operational lifetime, or Mean Time to Failure (MTTF) as it was termed. Pending further studies, Brown informed Secretary of the Air Force Eugene Zuckert that the final objectives of the program remained to be established.[34]

Eight years after Joe Knopow first interested Lockheed officials in infrared surveillance from space, the MIDAS program remained securely bracketed in research and development. At the close of 1963, while Air Force and Defense Department leaders considered what kind of follow-on effort should be pursued, Lockheed and Aerojet engineers set to work on the "research test series" of three satellites, identified as RTS-1, under the guidance of John Solvason and Marvin Boatright. The upper stage Agena booster-satellite used in this instance was the Agena D, a "standard Agena" that employed an improved rocket engine, common components tried and proved in other flight projects, and increased redundant features. Five feet in diameter and 34 feet long, the cylindrical vehicle closely resembled the Agena B. Power requirements for a six-month life, however, accounted for a significant physical difference. This Agena carried four solar arrays positioned for maximum sun intercept in all seasons: two fixed to the aft rack, as before, and two fixed to the forward rack, just aft of the infrared payload.[35]

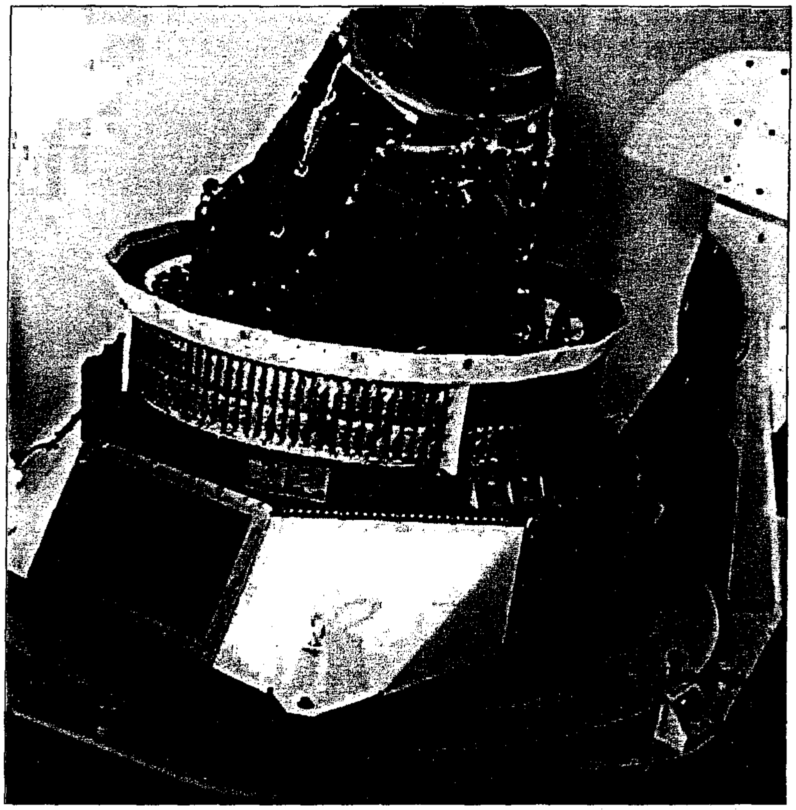

Figure 12. RTS-1 Infrared Sensor Payload.

Aerojet, now an Air Force Associate Contractor instead of a subcontractor to Lockheed, designed an improved infrared payload for the RTS-1 vehicles. It consisted of a Bouwers 8-inch aperture concentric telescope, improved spectral filters, and 442 lead sulphide detectors. These detectors, smaller than earlier versions, were compatible with an optical image quality of 30 seconds arc. Because of the increased number of channels, Lockheed and Aerojet introduced a multiplexer to the payload side of the slip ring, thus reducing substantially the number of mechanical crossings of the spin table. Two star sensors were also added to improve attitude information. As before, the payload rotated on its spin table at 6 rpm, and had a maximum slant range of 4200 miles at 2000 nm altitude. Plans called for launch of the three RTS-1 vehicles in late 1965 and early 1966.[36]

Air Force leaders, in the meantime, had lost none of their zeal for an operational MIDAS, and on 28 January 1964 Headquarters USAF issued Specific Operational Requirement No. 209 for just such a system. A few months later, on 15 May, the Space Systems Division in Inglewood released the development plan for the follow-on program, tentatively identified as RTS-2. This series of three flights would develop and demonstrate the technology needed in the 1970s for an operational system. That system was to be capable of worldwide surveillance directed toward detecting and warning of missile attack.[37] Yet another Air Force plan called for three more MIDAS detection test series (DTS) satellites to be built and launched in the late 1960s, before RTS-2 became available. That plan was axed in November 1964 during Defense Department FY 1966 budget deliberations.[38]

At the beginning of 1965 Air Force leaders, with the concurrence of the Director of Defense Research and Engineering, decided in favor of open contracting for the RTS-2 follow-on MIDAS program. Instead of consigning the enterprise to the existing spacecraft contractor, Lockheed Missiles & Space Company, it would be awarded through competitive procurement. This approach, its authors reasoned, would encourage new technical solutions to the problems of improved infrared detection and surveillance, and at the same time meet expressed Congressional sentiments that discouraged any automatic extension of the Lockheed MIDAS contracts. The Sunnyvale firm was by no means excluded, but it would have to compete to stay in the missile early warning business.

On 1 March 1965 Space Systems Division issued a Request for Proposal for an RTS-2 advanced system definition study of a multi-mission MIDAS. Eight firms replied, and three were selected to submit studies: Hughes Aircraft, Lockheed Missiles & Space Company, and TRW Space Technology Laboratories. Advances in electronics and demonstrated infrared payload performance strongly indicated that these vehicles could be operated successfully in stationary geosynchronous orbits—22,000 nm above the Earth. That meant fewer (albeit more expensive) satellites, and fewer ground stations would be needed in the operational system. Requirements therefore specified a geosynchronous orbit, with the RTS-2 satellites capable of detecting ICBM, SLBM, and MRBM launches, and of identifying their launch site. Each of these satellites was also to carry a secondary Vela-type nuclear detonation detection (NUDET) payload that could identify and report nuclear/thermonuclear explosions above ground, in the atmosphere, and in outer space.[39]

During the summer of 1965, while the three aerospace firms prepared definition studies of the RTS-2, officials in the office of the Director of Defense Research and Engineering and others on the Air Staff continued to evaluate MIDAS technology and its mission in the 1970s. An improved infrared payload, they reasoned, would also be able to detect the flash of nuclear and thermonuclear weapons of 20kt or greater yield at the Earth's surface. Coupled with a NUDET secondary payload, that made possible Missile Strike Reporting: direct observation of the detonation of U.S. strategic missiles in enemy territory with the position of detonation established within about five nm. This capability would become increasingly important as enemy defenses improved, eliminating any uncertainty about which missiles had actually struck their intended targets. Accordingly, the contractor proposals for the RTS-2 received at Space Systems Division in September 1965 were held without evaluation. On 15 November Headquarters USAF redesignated this follow-on effort, now also featuring missile strike reporting, as Program 266, eventually to become known as the Defense Support Program (DSP),* and issued for it a "preliminary" technical development plan.[40]

As 1966 commenced, John S. Foster, who had succeeded Harold Brown as the Defense Department's chief scientist in October 1965,† agreed that missile strike reporting would be a major objective of the DSP. On 12 January 1966 Headquarters USAF defined this capability: determining that a missile, launched against an enemy, had successfully penetrated defenses and detonated in the vicinity of the intended target. A few months later, this objective logically was expanded to include Attack Assessment, defined as the "detection and location of nuclear bursts directed against U.S. territory."[41] When requests for proposals for the DSP were reissued to the three aerospace contractors in April 1966,[42] the program's objectives had expanded markedly. They now embraced global early warning (which included detecting all types of ballistic missiles), launch point determination, detection of "nth country" launches, collection of intelligence data such as the staging and radiance levels of different missiles, and missile strike reporting, attack assessment, and nuclear test ban monitoring (Earth and space). These objectives were to be achieved by one or more DSP satellites operating in geosynchronous orbit, each with 15-month MTTF lifetimes. Although the program remained a research and development effort with the expanded mission to be achieved in the 1970s, it nonetheless presented a challenging order for the contractors.[43]

Hughes, TRW, and Lockheed submitted their proposals for the DSP in late June 1966. Of

*Both MIDAS and its follow-on DSP sported various numerical designations over time with the express purpose of disguising the effort and confusing outside observers. Thus, MIDAS also was called Program 239A, with the last three RTS flights identified as Program 461, in the mid-1960s, while DSP was known variously as Program 266, 949, and 627 later in that decade. To avoid this confusion, and because it refers specifically to the primary mission of detecting missiles, the name MIDAS has been applied throughout this history of the pre-DSP period.

†Harold Brown became Secretary of the Air Force on 1 October 1965.

the three, the Air Force on 23 August* selected TRW and Lockheed to present and negotiated their proposals, proceedings that concluded in late October. Aerojet, the infrared payload contractor, had teamed with TRW, while Lockheed had teamed for its payload with Baird-Atomic, Incorporated. The selection turned primarily on the integrated payload/spacecraft designs. Lockheed's proposal offered an improved version of the existing MIDAS, an Agena spacecraft stabilized on three axes in a nose-down attitude. The Baird-Atomic payload, mounted on a spin table and rotated at six rpm, would furnish the desired scanning to fulfill the specified missions. The TRW proposal, on the other hand, turned Lockheed's approach completely around. It too offered a cylindrical satellite in a nose-down attitude, but with the Aerojet infrared sensor rigidly attached to the forward end of the satellite and canted at 4.5 degrees from the longitudinal axis. Scanning would be achieved by spinning the entire vehicle at six rpm, using a novel "zero momentum" control system that employed a reaction wheel and gas jets. This approach eliminated the Lockheed spin table's rotating joint and the slip rings carrying power and data to and from the payload—features considered of dubious reliability at orbital lifetimes greater than one year. Withal, it was a relatively simple albeit elegant solution. And it won. The Air Force notified the contractors of TRW's selection on 15 December 1966, shortly after the launch of the last of three MIDAS RTS-1 satellites.[44]

Word of the award was sour news for Daniel Gribbon, Willis Hawkins, and other Lockheed officials who had steadfastly believed in the technical feasibility of MIDAS and nurtured the program in good times and bad over 10 trying years. It was especially so for the program manager,

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*A few days earlier on 20 August, John S. Foster, DDR&E, approved the DSP development plan that called for three R&D satellites and the expanded mission objectives, thus permitting the selection of contractors to proceed. (Rpt, Gerald T. Cantwell, *The Air Force in Space, Fiscal Year 1968, Part II,* Office of Air Force History, October 1970, p. 1).

Figure 13. Col Karl N. Retzer, last of the Air Force MIDAS-era Program Directors (1965-1966).

John Solvason, and his deputy, Hugh W. Batten, who had invested a substantial portion of their careers in the enterprise. To be sure, the Sunnyvale firm had treated MIDAS as a proprietary effort and resisted attempts to establish Aerojet as an associate contractor and full partner. But it must also be said that Lockheed had responded to an inordinate number of Defense Department changes and program redirections, met the demands of numerous scientific panels that evaluated MIDAS near-to-death, and erased the stigma of "failure" once used to characterize the entire endeavor. Indeed, two of the three Lockheed-Aerojet RTS-1 MIDAS satellites just launched in the preceding months, between June and November 1966, were performing almost flawlessly. Now, with technical success apparently in hand, the ultimate prize—contracts for the follow-on program—had been snatched away and awarded to others. That word was unquestionably a most bitter pill to swallow in Sunnyvale, though the taste of it might still be sweetened if Lockheed's RTS-1 satellites performed reliably over time, and if TRW and Aerojet efforts proved the concept for an operational system in geosynchronous orbit.

The first of the three RTS-1 MIDAS satellites had been launched from Vandenberg AFB back on 9 June 1966, a few days before the Air Force began evaluating contractor proposals for the follow-on DSP. (Originally scheduled for launch in late 1965, the flight had been delayed by a variety of technical difficulties and a one-month strike of employees at Aerojet's plant in Azusa, California, where the payload was fabricated.) Lockheed's Agena D booster-satellite by 1966 had become one of the most trusted and reliable upper stage rockets used in America's military and civilian space programs, best known perhaps as the target vehicle in the Gemini manned missions of the day. On 9 June, however, the Agena's Bell rocket engine failed to ignite for its second burn and, instead of a 2000 nm circular polar orbit, the satellite remained in a highly elliptical parking orbit with a perigee of 108 nm and an apogee of 2,246 nm. Worse, the Agena tumbled and its attitude control gas quickly exhausted. No useful tests of the infrared payload could be performed, and a few months later, on 3 December 1966, the satellite dipped into the Earth's lower atmosphere over Australia and incinerated.[45]

Launch of the last two MIDAS satellites followed rapidly. The second and third RTS-1 vehicles rose from Vandenberg AFB on 19 August and 5 October 1966, achieved the intended circular polar orbits, and operated successfully for 11 and 12 months, respectively, easily exceeding the six-month MTTF lifetime planned for them. During this period these two spacecraft also detected *all* Soviet and U.S. ballistic missiles launched within their field of view—139 rocket launches—and identified four Soviet launch sites. This accomplishment was secured in the face of global cloud cover once thought to preclude space-borne missile defense alarm. By late 1967 America's leaders could acknowledge the program to be a national resource. One can only speculate what effects these spectacular flight test results might have had if the follow-on contract selection had occurred one year later. "At this juncture," Marvin Boatright, Aerojet's MIDAS program manager frankly confided, "it would have been possible to have configured an operational deployment" (using the Lockheed/Aerojet system).[46] Whatever the "would have beens," at the end of 1966 TRW and Aerojet were the contractors of record for the follow-on DSP.

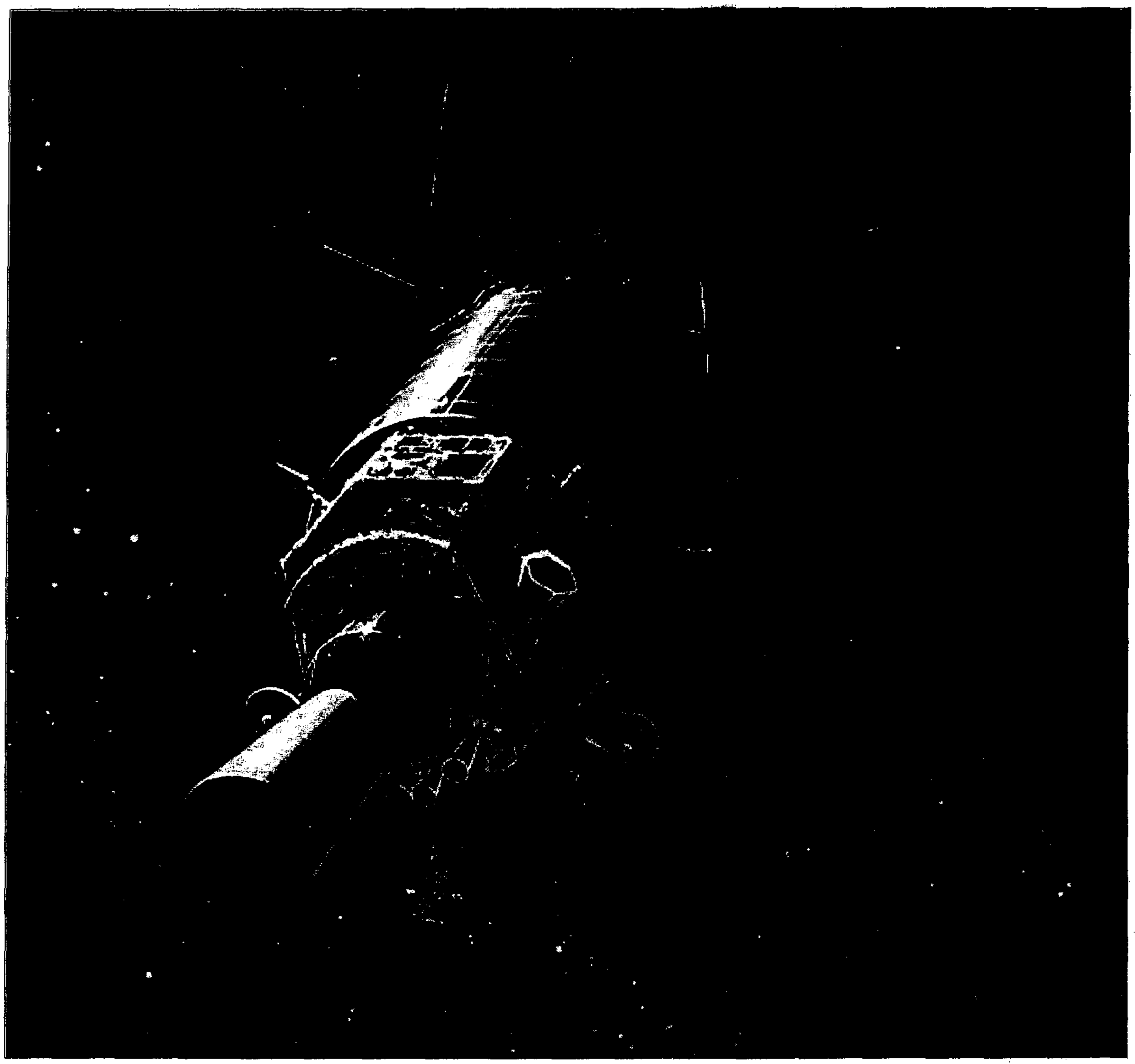

Figure 14. The DSP satellite, MIDAS's successor.

DATE	LAUNCH VEHICLE	LAUNCH SITE	SPACECRAFT	PAYLOAD	EVALUATION
2-26-60	Atlas 29D	CCAFS LC-14	Agena A 1008	MIDAS 1	Launch Failure (Atlas/Agena)
5-24-60	Atlas 45D	CCAFS LC-14	Agena A 1007	MIDAS 2	On-Orbit Failure (Attitude Control)
7-12-61	Atlas 97D	PALC 1-2	Agena B 1201	MIDAS 3	On-Orbit Failure (Electrical Power)
10-21-61	Atlas 105D	PALC 1-2	Agena B 1202	MIDAS 4	Improper Orbit (Atlas)
4-9-62	Atlas 110D	PALC 1-2	Agena B 1203	MIDAS 5	On-Orbit Failure (Electrical Power)
12-17-62	Atlas 131D	PALC 1-2	Agena B 1205	MIDAS 6	Launch Failure (Atlas)
5-9-63	Atlas 119D	PALC 1-2	Agena B 1206	MIDAS 7	Success (47 days)
6-12-63	Atlas 139D	PALC 1-2	Agena B 1204	MIDAS 8	Launch Failure (Atlas)
7-18-63	Atlas 75D	PALC 1-2	Agena B 1207	MIDAS 9	Success (11 days)
6-9-66	Atlas 7201 (SLV-3A)	VAFB SLC-3E	Agena D 1351	RTS-1 F1	Launch Failure (Agena)
8-19-66	Atlas 7202 (SLV-3A)	VAFB SLC-3E	Agena D 1352	RTS-1 F2	Success (325 days)
10-5-66	Atlas 7203 (SLV-3A)	VAFB SLC-3E	Agena D 1353	RTS-1 F3	Success (372 days)

Abbreviations: CCAFS = Cape Canaveral AFS; LC = Launch Complex; MIDAS = Missile Defense Alarm System; PALC = Point Arguello Launch Complex; RTS = Research Test Series; SLC = Space Launch Complex; SLV = Standard Launch Vehicle; VAFB = Vandenberg AFB

Note: This table does not include at least eight Discoverer/CORONA flights that mounted radiometers and that gathered infrared background data for the MIDAS program: Discoverer/CORONA 19 (12-20-60), 21 (2-18-61), 49 (8-28-62), 52 (9-29-62), 57 (12-14-62), 73 (11-9-63), 92 (2-25-65), and 99 (9-2-65).

ACKNOWLEDGEMENTS

A number of people assisted in the preparation of this history, and I am indebted to them. Special thanks are owed original participants who contributed their recollections in person or by phone, and commented on initial drafts, particularly Joseph Knopow and Marvin Boatright. Richard Friedman at TRW helped with comment and documentation. Upon declassification of the MIDAS Program in 1999, some ten years after I prepared this history, Harry Waldron, the Air Force Historian at SMC, kindly permitted me to use the Table of MIDAS launches that he had prepared, which appears above. Mr. and Mrs. Jeffrey P. Knopow and Major James Rosolanka, USAF, provided the illustrations that appear in this work.

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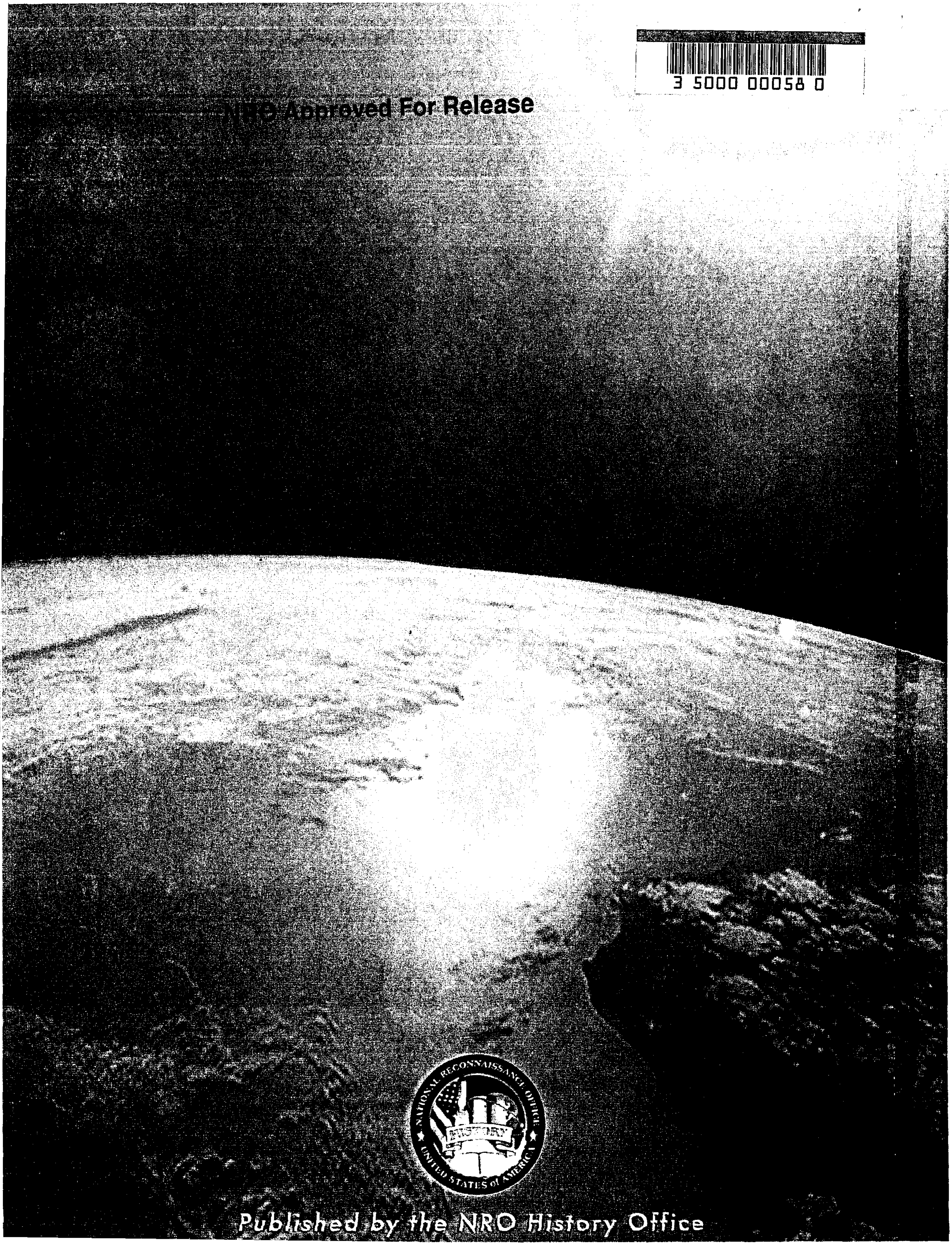

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