CASE II

STRANGLED INFANT: THE BOEING X-20A DYNA-SOAR

by

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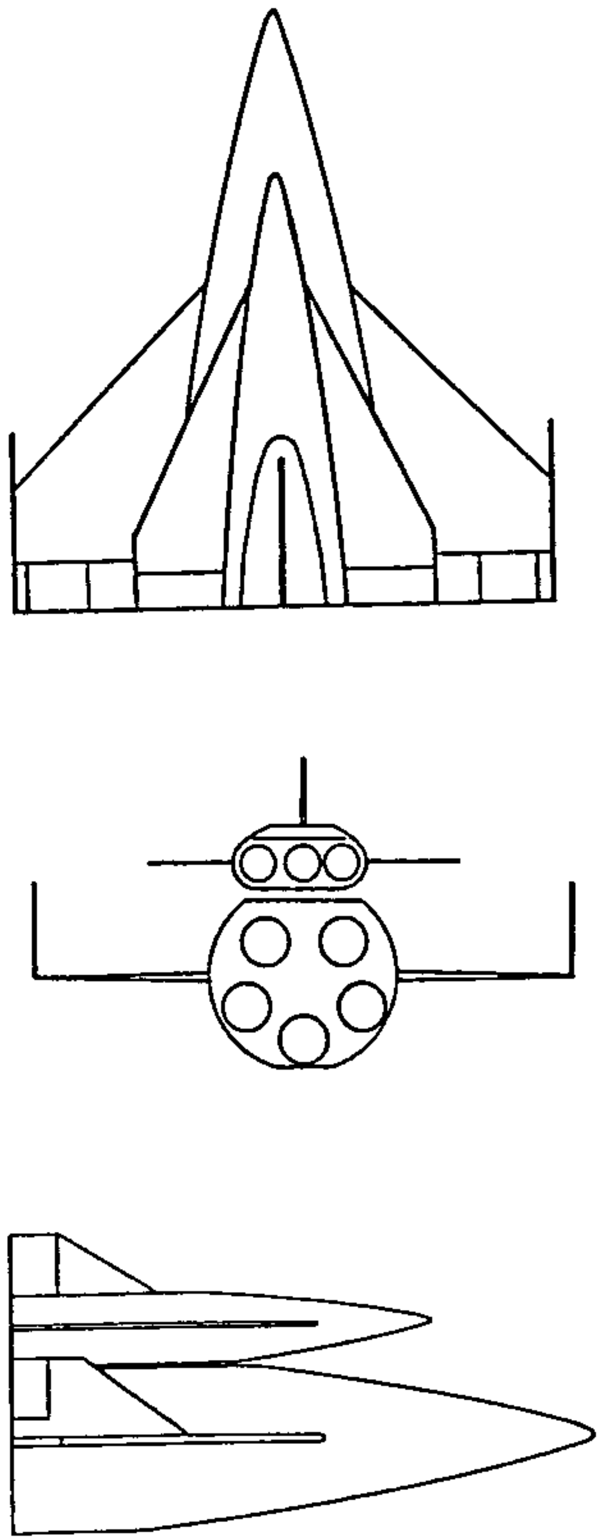
EDITOR'S INTRODUCTION

The X-20 is a particularly poignant case study in the history of hypersonic lifting reentry. No project was ever undertaken with more enthusiasm by its advocates, and no project was ever more callously treated by bureaucratic forces beyond the research and development community. X-20--a shapely hypersonic delta glider--materially advanced understanding of the requirements and the technology needed for lifting reëntry vehicles, yet it itself never had the opportunity to demonstrate what it could do.

The X-20 program was conceived at Wright-Patterson Air Force Base, with a healthy assist from external organizations including the Bell Aircraft Corporation and the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics (now the Langley Research Center of the National Aeronautics and Space Administration). Its conception coincided with a generalized national interest in hypersonic vehicles for missions ranging from transportation to orbital supply. Even before the X-15 had entered fabrication, devotees of winged reentry were studying a variety of proposals for orbital lifting reentry vehicles, and, indeed, even interplanetary ones. Some of these orbital studies were military in nature, and eventually led into the Dyna-Soar program discussed subsequently. Others were civilian. Most were, in light of subsequent work, completely impractical, if visionary. In August 1952, the Executive Committee of the National Advisory Committee for Aeronautics appointed a hypersonic study group under the chairmanship of Clinton Brown. This body reported to NACA Headquarters in June 1953, recommending that the NACA undertake heating studies, and fire rocket-propelled hypersonic models. It optimistically predicted the near-term development of hypersonic boost-glide intercontinental aircraft. (Most technical studies in the 1950s suffered from an excess of optimism that the very real problems encountered in designing such craft could be quickly overcome). Even more ambitious and idealistic were the fantastic conceptualizations of Wernher von Braun and Walter Dornberger. Their work naturally drew upon the previous Peenemünde A-4b--A-12 studies. In a series of books published in the early 1950s, A-4b--like and similar craft routinely appeared performing a variety of space missions, usually in the exquisite and seductive paintings of Chesley Bonestell. In 1951, space travel buffs had organized a symposium at the Hayden Planetarium. Out of this enthusiastic meeting came a number of optimistic articles printed in Collier's magazine, and later reprinted in a single volume, Across the Space Frontier. In this work, von Braun described a theoretical three-stage launch vehicle capable of placing 36 tons in earth orbit. The third stage was a canard shuttle-like aircraft having five rocket engines fueled with nitric acid and hydrazine, with provisions for a pilot and crew, and having a retractable landing gear. It spanned 156 feet, with a length of 77 feet. Von Braun predicted that reentry heating would turn the craft cherry-red, but that this could be overcome by using steel. He elaborated upon this concept in a 1956 book, The Exploration of Mars. Here, von Braun and rocket enthusiast Willy Ley conceived constructing a large flying-wing interplanetary spacecraft spanning 450 feet that could coast from earth orbit to Mars, then enter the Martian atmosphere and fly down to a landing. Its nose section was an ascent rocket that would return the crew to Martian orbit preparatory to the return to earth; the rest of the vehicle would be left on the surface of Mars. Von Braun also conceptualized the building of a smaller delta-wing passenger spacecraft that would support earth orbit operations; this craft looked much like an extrapolation of 1950's jet fighters such as the Convair F-102A and Gloster Javelin. Dornberger, meanwhile, had expanded upon his own boost-glide studies. In 1957, in collaboration with Krafft A. Ehricke, Dornberger conceived of a two-stage passenger-carrying Shuttle-like transport drawing heavily on Bell's Bomi studies (to be discussed subsequently). (Figure 1).

Figure 1



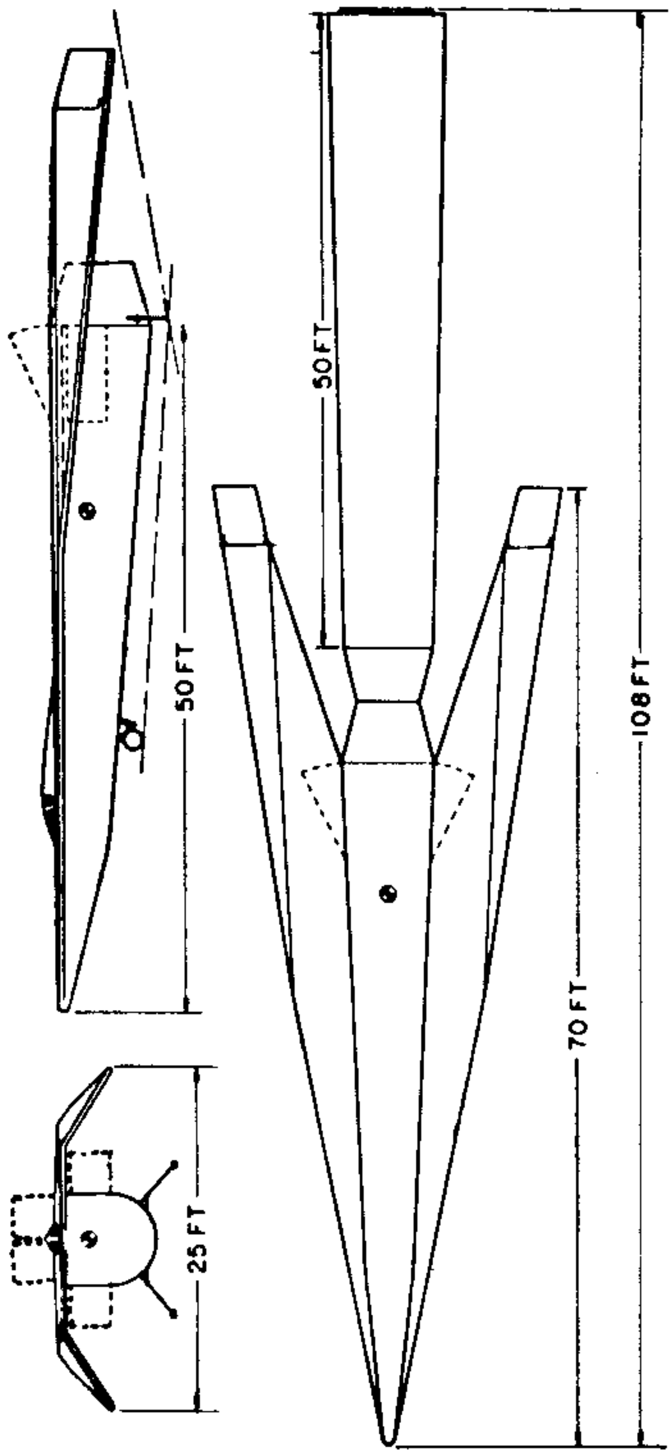
DORNBERGER-EHRICKE HYPERSONIC TRANSPORT

The stages were mounted in piggyback fashion, with the ventral stage having five rocket engines and the dorsal (passenger-carrying stage) having three. Each stage had delta wings for boost-glide flight. Dornberger and Ehricke anticipated that such a craft would take off with both stages firing and 130 seconds after launch, the lower stage would separate and glide back to land, piloted by its own crew. The smaller dorsal stage would continue onwards, reaching a peak altitude of 27.5 miles and crossing the United States in 75 minutes. Clearly, by the mid-1950s, then, a number of lifting reentry studies were underway, though the practicality of these studies varied widely. What remained to be done was for the industry and government to join forces on a suitable development program that could serve as an actual technology demonstrator.[1]

Already, by 1957, the Ames Aeronautical Laboratory of the NACA had conceived one such likely "beyond X-15" Mach 10 technology demonstrator that would be piloted and air-launched from a Boeing B-36 carrier aircraft for initial trials up to Mach 6. For velocities beyond this, the plane would be launched vertically as the second stage of a two-stage combination, the first stage being a 150,000 lb thrust North American Rocketdyne XLR89-NA-1 engine. Booster separation would occur at 100,000 feet and Mach 6, and the research airplane would then fire up its own XLR99 engine and scoot across the southern United States from Florida to California. Figures 2, 3, and 4 show a schematic view of the research vehicle, its B-36 launch aircraft, and the proposed transcontinental flight path. Interestingly, the Mach 10 design featured a high wing, a sharply swept delta wing with down-turned tips _a la_ the later XB-70A, and would employ a mix of radiative cooling and an internal liquid cooling system. A great debate broke out within the NACA on the merits of high wing vs. flat-bottom low wing, a struggle that low-wing advocates subsequently won. (Ironically, one could "flip" the drawing of the Ames proposal on its back and see a reasonably acceptable flat-bottom hypersonic glider of the sort that occupied so much attention of Air Force, NACA/NASA, and industry studies in the 1950s through the present day). While the Ames Mach 10

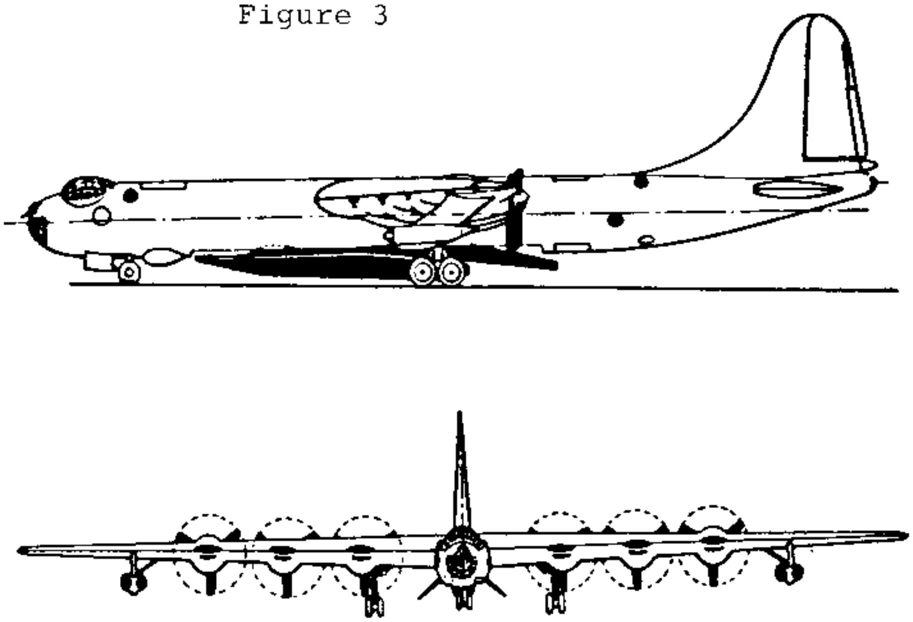
Figure 2

	2-stage; ground launch	1-stage; air launch
Performance:		
Velocity	11,000 ft/sec	5,000 ft/sec
Altitude	135,000 ft	110,000 ft
Range	2,000 N. miles	400 N miles
Weight:		
Gross weight	110,000 lb	33,000 lb
Weight fuel	90,000 lb	18,000 lb
Weight at burnout	15,000 lb	15,000 lb
Powerplant:	1st stage	2nd stage
Rocket motor	XLR89-NA-1	XLR99-RM-1
Thrust	150,000 lb	57,000 to 17,000 lb



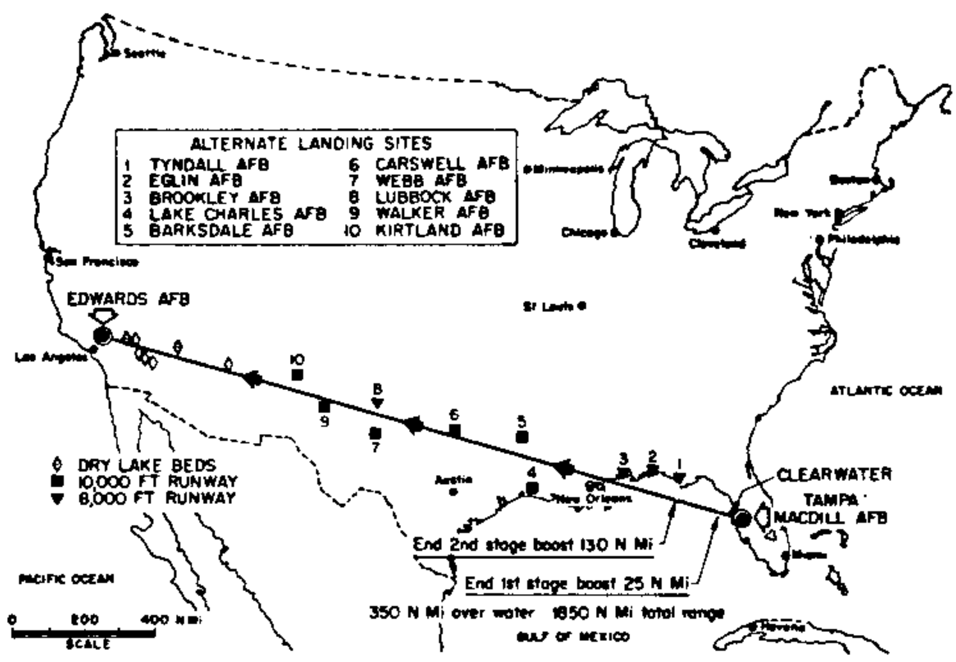
NACA AMES MACH 10 TECHNOLOGY DEMONSTRATOR (1957)

Figure 3



AMES MACH 10 DEMONSTRATOR AND B-36

Figure 4



FLIGHT CORRIDOR FOR AMES MACH 10 DEMONSTRATOR proposal subsequently went nowhere, it did serve to focus the attention of a major NACA center on one possible hypersonic configuration beyond the X-15, and came at a time when a climate was building that would spawn the cancelled X-20A Dyna-Soar program, the "Round Three" that followed the X-15, and the most ambitious lifting reentry effort prior to the actual Shuttle itself.[2]

Dyna-Soar's origins were nurtured amid this supportive general climate, and specific research and development initiatives undertaken by the Air Force and private industry. In 1952, the Bell Aircraft Corporation had proposed developing a boost-glide bomber-missile dubbed Bomi. With further refinement, Bomi evolved into an intercontinental three-stage "piggyback" reconnaissance bomber similar to later Shuttle "triamese" formulations. William Lamar, a distinguished engineer whose career in military aircraft development dated to the early days of the Second World War, was then in charge of future advanced bomber development studies for the Air Force at Wright-Patterson AFB. He recognized there were several approaches one could take towards future bomber and "recce" development; one, the so-called "vista" (or U-2) approach, envisioned going for maximum altitude in lightly loaded and relatively slow vehicles. Another approach took the other extreme: staying very low and moving very fast (this approach led to consideration of a proposed Mach 3 on-the-deck missile dubbed Pluto). The more reasonable approach, however, lay in extrapolating the already higher-and-faster trend in bomber design, moving from the B-29 to the B-36, the B-47, the B-52, and (by the mid-1950s) the Mach 2 B-58 then undergoing initial flight testing. To Lamar, the advantages of moving beyond the supersonic to a hypersonic strike/recce vehicle were obvious: one got orbital range and virtual invulnerability from interception.[3] At Air Force suggestion, Bell followed Bomi with a two-stage Mach 15 reconnaissance vehicle dubbed System 118P. Both Bomi and System 118P influenced Bell's next design effort, a reconnaissance system dubbed Brass Bell. After evaluating and proving generally receptive to these studies, the Air Force next funded a number of industry investigations of reconnaissance and strike boost-gliders. In 1956, the Air Force Air Research and Development Command launched a feasibility study of an orbital winged rocket bomber nicknamed Robo. To support Robo and the earlier Brass Bell, the service proposed developing a piloted boost-glide research aircraft known as Hywards. Contractors working with the Air Force on these efforts included Bell, Boeing, Convair, Douglas, North American and Republic. In November 1956, the Air Force asked the NACA to review the service's boost-glide aircraft studies. In response, NACA Director Hugh L. Dryden formed a "Round Three" (Round One being the early X-series and Round Two the X-15) steering committee which evaluated the various projects and then recommended to the Air Force, in September 1957, that the service sponsor development of a flat-bottom hypersonic delta glider. On October 4, 1957, the Russians launched Sputnik; on October 10, the Air Force consolidated Robo, Brass Bell, and Hywards into a single three-phase research program called Dyna-Soar, for "dynamic soaring," what Sänger had termed skipping reentry. On October 15, a "Round Three" conference opened at NACA's Ames Aeronautical Laboratory, and conferees eventually endorsed the recommendations of the Dryden steering committee. A minority favored a purely ballistic H. Julian Allen-type blunt body design having nonlifting characteristics; this marked the genesis of what eventually evolved into the Mercury spacecraft. Another minority favored development of an Alfred Eggers or Eugene Love lifting-body spacecraft. (Eventually, as the studies of the 1960s clearly reveal, all three paths, ballistic, winged, and lifting body, would be pursued by government and industry enthusiasts). On December 21, 1957, the headquarters of the Air Force's Air Research and Development Command (ARDC) issued System Development Directive 464L for development of Dyna-Soar's first phase, envisioned as a simple delta-wing single-seat boost-glider technology demonstrator.[4]

Nine contractor teams eventually responded with proposals, and the respondents represented essentially a Who's Who of American aviation: Bell, Boeing, Chance Vought, Convair, General Electric, Douglas, Lockheed, McDonnell, Martin, North American, Northrop, Republic, and Western Electric. After review, four of the nine were selected to work as two teams: a Martin-Bell team, and a Boeing-Vought team. The Air Force directed Boeing-Vought and Martin-Bell to proceed with additional detailed studies, and, as a result, declared Boeing the winner on November 9, 1959. Martin received a go-ahead to develop the launch booster, a modified Titan ICBM. Bell, the firm whose work had inspired much of the program, wound up with nothing but some subcontracts.* The Air Force selected Lamar to run the program for the service; his NACA/NASA counterpart was John V. Becker, a distinguished physicist and the "father" of the X-15. Two better individuals could not have been selected, and they worked superbly together.[5]

For a brief while, Dyna-Soar went through some major convolutions involving its external shape, including a brief fling with one configuration having ventral fins and an angularity of design that suggested the fantastic 1930's science fiction of Buck Rogers and Flash Gordon. One of these early schemes is shown in Figure 5--a bizarre eight-engine delta booster lugging the initial Dyna-Soar configuration (consisting of the orbiter and a booster stage) aloft, then firing it into orbit from 75,000 feet. Such grandiose schemes died amidst the need for practical design. Eventually, Dyna-Soar emerged as a radiative-cooled slender delta having a flat Sänger-like bottom, a rounded and tilted nose, and twin end plate vertical fins. (Figure 6). The glider utilized a René 41 nickel superalloy primary structure, a columbium alloy heat shield, a graphite and zirconia nose cap, and molybdenum alloy leading edges. Unfortunately, the program suffered from a

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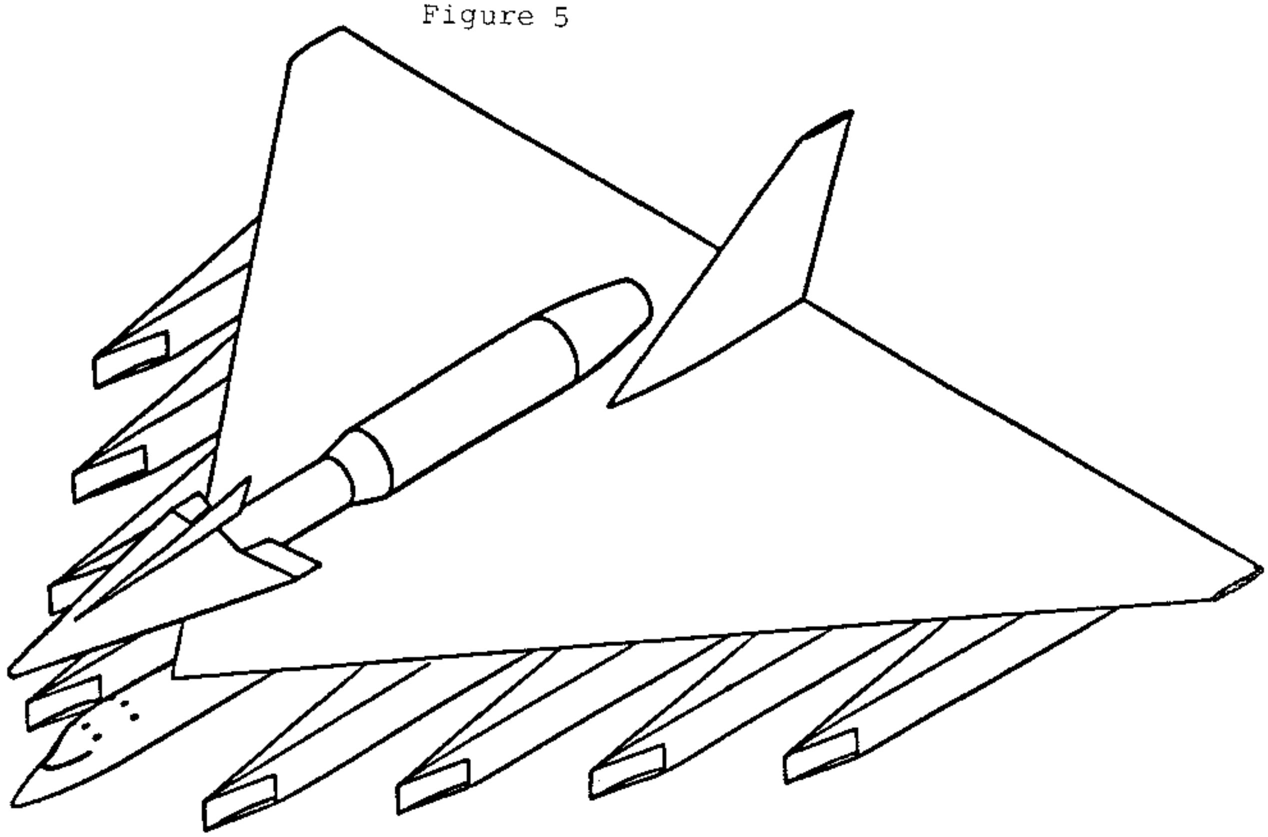
*Eventually, Vought's share of Dyna-Soar involved primarily work on the nose cap. Ironically, Boeing's Dyna-Soar ultimately more closely resembled the original Bell concept than it did Boeing and Vought's winning entry in 1959.

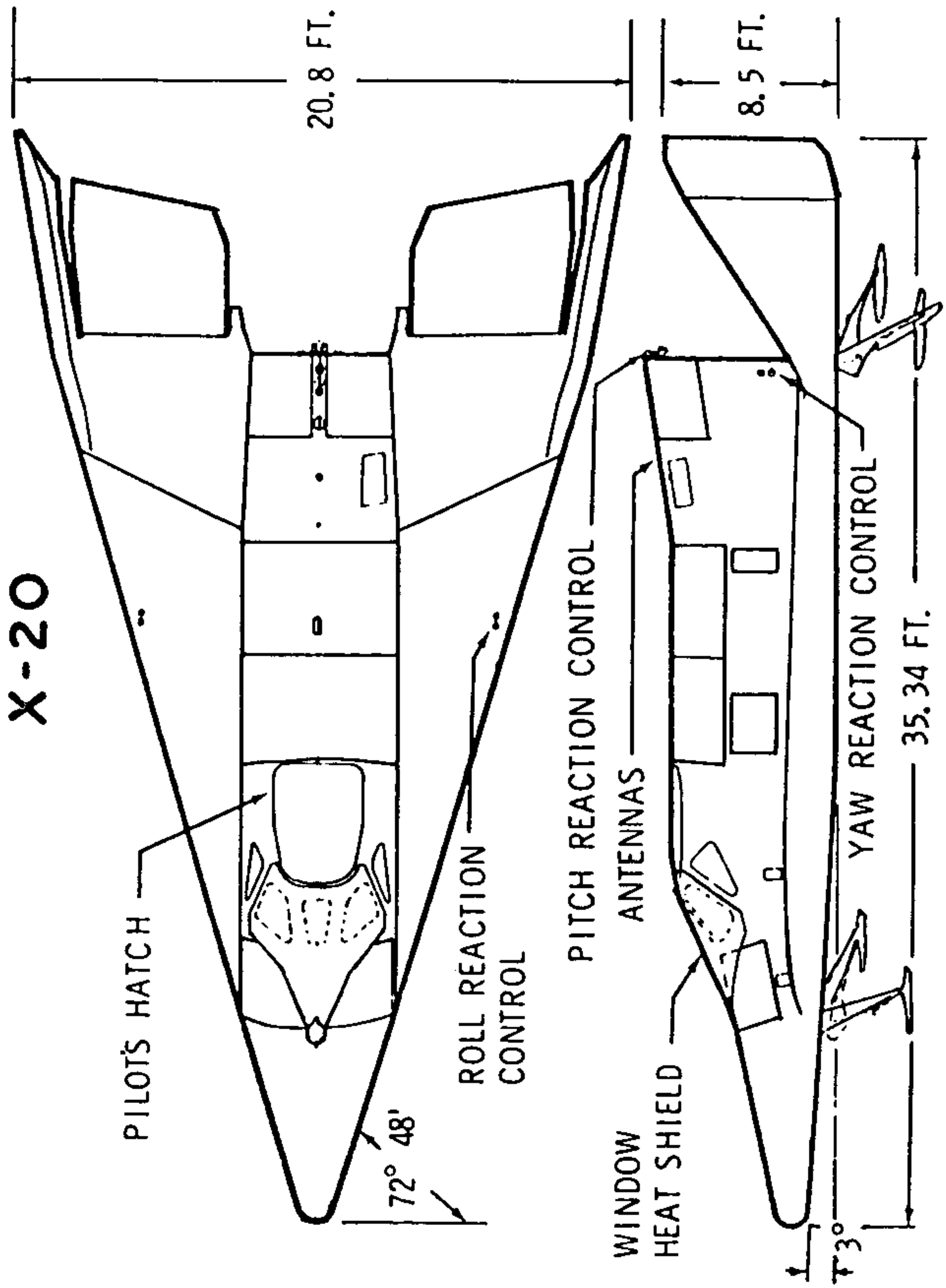
Figure 5



Payload weight:	145,000 lbs.
Launch gross weight:	585,000 lbs.
Booster gross weight:	440,000 lbs.
Booster empty weight:	276,000 lbs.
Launch altitude:	75,000 ft.
Launch velocity:	4,000 ft./sec.

EARLY DYNA-SOAR AIR-LAUNCH CONFIGURATION

Figure 6



THE X-20 BOOST GLIDER

perceived (if not actual) lack of clear definition (largely to outsiders) of what its goals should be. At the highest levels within the Air Force, as well as within the prestigious Aerospace Vehicles Panel of the USAF Scientific Advisory Board, disagreements existed over what role Dyna-Soar should play in the steadily growing American manned spacecraft effort. Critics of Dyna-Soar argued that semi-ballistic or ballistic spacecraft (such as growth versions of the planned Gemini spacecraft) could carry a much larger useful payload into orbit. In June 1962, the Air Force designated Dyna-Soar as the X-20A, primarily to emphasize its research function. For a while, X-20A faced sniping criticism from partisans within the USAF Space Systems Division (SSD) favoring development of a rival--a small piloted lifting body for satellite inspection and space logistics known as SAINT II. Though Dyna-Soar weathered this storm while SAINT II itself succumbed, it was clear that Dyna-Soar was losing its appeal. Privately, Secretary of Defense Robert S. McNamara's senior advisors concluded that Dyna-Soar's research objectives could be most expeditiously, safely, and economically met by small reentry models and by the Manned Orbiting Laboratory (MOL) program, a "bluesuit" spin-off of the Gemini program. X-20's support weakened rapidly over the fall of 1963, and McNamara canceled it on December 10, 1963, in favor of proceeding with MOL. (Ironically, MOL itself collapsed subsequently). At the time of its cancellation, the X-20A was about 2½ years and an estimated $373 million away from its first flight. Four hundred and ten million dollars had already been expended. The cancellation decision is one that is still hotly debated; in any case, Dyna-Soar greatly accelerated progress in hot structures technology, the aerodynamics of delta reentry shapes, hypersonic design theory, and other information directly applicable to the present Shuttle. It was, therefore, a useful exercise despite its termination.[6]

Dyna-Soar's story is a disturbing one, as the following case study shows. Here was a well-thought-out and well-directed program (at least at the USAF and NASA "worker bee" level) that received as its reward summary execution without fair trial. In the minds of program participants, what is more disturbing are overtones of internal dissension--for example, lukewarm support from Space Systems Division and SSD's technical advisor, the Aerospace Corporation, coupled with lukewarm support from senior levels within the Air Force, including General Bernard Schriever and Lt. Gen. H. M. Estes. "If we could have stuck with von Braun," Lamar recently recalled, "we'd have had it made."[7] At the civilian secretary level within the Department of Defense, X-20 had few supporters; one notable exception was Eugene Zuckert, Secretary of the Air Force. In his last meeting with Secretary of Defense Robert McNamara, Lamar faced a typical "economic" question from Harold Brown: "You want $1 billion for ten shots: that's $100 million per shot. What can you do that is worth $100 million? What can you do that SAMOS can't?"[8] The Secretary of Defense and his immediate staff, with rare exception, turned a blind eye to carefully presented arguments emphasizing the importance of X-20 as a technology demonstrator, and, as a result, after 1962, the outcome was obvious: Dyna-Soar died.

Perhaps Dyna-Soar suffered from the climate of space development in the early 1960s. In 1961, Yuri Gagarin had orbited the earth in a ballistic capsule, and Project Mercury had followed that development approach (though with greater sophistication). One of Dyna-Soar's strongest arguments in the late 1950's was the opportunity it offered to match the Soviets in space and perhaps beat them to a manned orbital flight. A letter from the Deputy Chief of Staff for Development of the Air Force to the Commander of the Air Research and Development Command (the predecessor of today's Air Force Systems Command) stated that:[9]

> A manned orbital flight, whether by a glide vehicle or by a minimum altitude satellite essentially outside the earth's atmosphere, is a significant technical milestone in the USAF space program. It is also vital to the prestige of the nation that such a feat be accomplished at the earliest technically

practicable date--if at all possible before the Russians.

The same letter directed continuation of the Air Force-NACA research aircraft partnership "which has proven so productive in earlier programs of the X-airplane series." It also recognized that the technical problems involved in a boost-glide orbital vehicle might necessitate using a ballistic satellite instead in the interests of time and safety. Possibly, once Gagarin had flown and once Mercury stood poised (as it were) on the launch pad, Dyna-Soar lost some psychological support. Then, of course, was the unfortunate acronym "Dyna-Soar:" it stood for dynamic soaring, and made perfect technical sense, but sounded too much like dinosaur: big, complex, slow, and headed for extinction.

Dyna-Soar's cancellation undoubtedly set back the pursuit of lifting reentry technology in the United States by at least a decade. Even if it had never flown an orbital flight, it would have proven a tremendously valuable hypersonic research aircraft follow-on to the X-15, and thus deserved aggressive support within DoD rather than shortsighted cancellation. The following case study was written during and after the cancellation by Dr. Clarence J. Geiger of the then-Historical Division, Information Office, Aeronautical Systems Division. It has been expanded to include a useful analysis of the X-20 work undertaken by the Boeing Company, emphasizing technical accomplishments. The case study offers a particularly good overview of the six critical periods in the development of the X-20: the debate over the nature of the program; the Phase Alpha studies; award of development contracts for the airframe and booster; slippage, rival efforts, and pressure to cancel; the shift to a more defined research focus; and, finally, the continued debate leading to cancellation in December 1963.

NOTES

1. For Brown study group report, see C. E. Brown, et. al., "A Study of the Problems Relating to High-Speed High-Altitude Flight," (Hampton: NACA Langley Laboratory, June 25, 1953), in the files of the NASA Langley Research Center. Von Braun's conceptual studies are detailed in Willy Ley and Chesley Bonestell's The Conquest of Space (New York: The Viking Press, 1956); Wernher von Braun "Prelude to Space Travel," in Cornelius Ryan, ed., Across the Space Frontier (New York: The Viking Press, 1953), pp. 12-70; Willy Ley and Wernher von Braun, The Exploration of Mars (New York: The Viking Press, 1956). The Dornberger-Ehricke project is discussed in Willy Ley's Rockets, Missiles, and Men in Space (New York: The Viking Press, 1968), pp. 449-450. A generally useful introduction to the lifting reentry work of the 1950's is E. P. Smiths's "Space Shuttle in Perspective: History in the Making," presented at the XIth Annual Meeting of the American Institute of Aeronautics and Astronautics, Washington, D.C., Feb. 24-26, 1975.

2. Ames laboratory staff, Preliminary Investigation of a New Research Airplane for Exploring the Problems of Efficient Hypersonic Flight (Moffett Field, CA: NACA Ames Aeronautical Laboratory, 18 January 1957), passim. Copy in the files of the History Office, NASA Lyndon B. Johnson Space Center, Houston, Texas.

3. Interview with William Lamar, September 18, 1986.

4. For Dyna-Soar origins, see Clarence J. Geiger, History of the X-20A Dyna-Soar, v. I (Historical Division, Aeronautical Systems Division, Air Force Systems Command, Oct. 1963), pp. ix-x, 4-28; Kleinknecht, "The Rocket Research Airplanes," pp. 209-210; Eugene M. Emme, Aeronautics and Astronautics: An American Chronology of Science and Technology in the Exploration of Space, 1915-1960 (Washington, D.C.: NASA, 1961), pp. 83, 85; the ballistic vs. lifting reentry approach and USAF-NACA relationships on the emerging Dyna-Soar effort is discussed in Loyd S. Swenson, James M. Grimwood, and Charles C. Alexander, This New Ocean: A History of Project Mercury (Washington, D.C.: NASA, 1966), pp. 71, 73-74. See also Robert R. Gilruth, "From Wallops Island to Project Mercury, 1945-1958: A Memoir," in R. Cargill Hall, ed., Essays on the History of Rocketry and Astronautics: Proceedings of the Third Through the Sixth Symposia of the International Academy of Astronautics, v. II (Washington, D.C.: NASA, 1977), pp. 463-465.

5. Geiger, History of the X-20A Dyna-Soar, pp. 29-49; letter from John L. Wesesky to author, Oct. 23, 1985.

6. Ibid., pp. 55-121. Details of the cancellation can be found in Geiger's subsequent History of Aeronautical Systems Division, July-Dec. 1963, v. III, Termination of the X-20A Dyna-Soar (Historical Division, Aeronautical Systems Division, Air Force Systems Command, Sept. 1964), passim. For Congressional and DoD

criticism of the Dyna-Soar program and its impact upon AF planners, see Robert Frank Futrell, Ideas, Concepts, Doctrine: A History of Basic Thinking in the United States Air Force, 1907-1964, v. II (Maxwell AFB: Aerospace Studies Institute, Air University, June 1971), pp. 786, 792-795. The secretarial-level view of the Dyna-Soar cancellation can be found in a memo for the Secretary of Defense from Robert C. Seamans, Jr., and Harold Brown, signed Jan. 29-31, 1964, and in the files of the NASA Johnson Space Center History Office. Finally, Boeing report D2-23418, "Summary of Technical Advances: X-20 Program" (Seattle: The Boeing Company Aerospace Division, July 1964) contains a comprehensive listing of X-20 technical accomplishments, as well as indications of what work remained to be done. I have also benefitted by discussing the cancellation with John V. Becker, chief of hypersonic research for the NASA Langley Research Center, and the major NASA "player" during the Dyna-Soar effort, and Col. Curtis L. Scoville, USAF (ret). One interesting perspective on Dyna-Soar is that of the USAF Scientific Advisory Board; key SAB reports clearly indicate the growing disenchantment and uncertainty affecting the program. See, for example, SAB, "Report of the Aero and Space Vehicles Panel on Dyna-Soar," (Jan. 1960), pp. 1-5; SAB, "Memorandum of the Scientific Advisory Board Aero & Space Vehicles Panel on Dyna-Soar," (Dec. 1960), p. 1; SAB, "Report of the Scientific Advisory Board Aero and Space Vehicles Panel on Dyna-Soar Phase Alpha Review," (Apr. 15, 1960), pp. 1-7; SAB, "Report of the Scientific Advisory Board Aerospace Vehicles Panel," (Nov. 1962), pp. 4-5. Copies of these SAB reports are in the files of the SAB, Hq. USAF, Washington, D.C.

7. Lamar interview.

8. Ibid.

9. Ltr., USAF/CS to ARDC/CC, 31 Jan 1958, copy in the "Hypersonic Aircraft" file, NASA History Office, Washington, D.C.

CHAPTER I

BOMI TO DYNA-SOAR

By April of 1945, the Allied drive across Northern Europe had effectively countered Nazi Germany's terror-weapon campaign against the civilian population of Great Britain, Holland, Belgium, and France. The V-1 cruise missile, the so-called "buzz bomb," was largely a thing of past, save for ones air-launched by Heinkel bombers dodging Allied nightfighters over the North Sea. The V-2 ballistic missile likewise was at the end of its military career. The architect of the infamous V-2 and Nazi Germany's missile program, Generalleutnant Walter Dornberger, had taken his emigre band of rocketeers from Peenemünde on the Baltic coast down to the recesses of Bavaria. Now they awaited the arrival of American forces, confident--one might say arrogantly so, given the immense contribution to human suffering that these individuals had made, from the slave labor camp at Nordhausen where V-2s were made to the devastated rubble of London and Antwerp where the missiles had landed--that their services would continue largely uninterrupted in the postwar years. While the V-2 could not have altered the outcome of the war, it had offered a radical vision of future warfare with its dramatic change of the concept of weapon delivery.

At Peenemünde, the V-2 had been antiseptically known as the A-4--the fourth in a series of ever-larger rockets developed by a team led by Dr. Wernher von Braun and Dr. Walter Thiel. Thiel had died in a Royal Air Force bombing raid against the weapons research center in August 1943, and with his death the Nazi rocket team lost their best propulsion expert. The A-4, dubbed V-2 (for Vergeltungswaffe Zwei--"Revenge Weapon Two") by Adolf Hitler, had first struck out at the cities of Europe in September 1944, and from then until the campaign drew to a close, 3,000 of the supersonic missiles had roared aloft. The Peenemünde team, carefully choosing to turn a blind eye to the pointless frightfulness of the V-2 campaign, constantly chose to see their work leading towards the stars, though they did not let even this vision prevent them from enjoying the success of their labor; "When the first V-2 hit London," von Braun recollected after the war, "the champagne flowed."[1]

There was little reason for champagne in Nazi Germany as 1944 wended its way into 1945, and the developers of the V-2 quickly realized that the loss of coastal launch sites would quickly remove Allied cities from the reach of German terror weapons. In late 1944, drawing upon work dating to 1943, von Braun and Ludwig Roth married the V-2 to a sharply swept low aspect ratio wing, generating a "boost-glide" weapon that could be propelled into the upper atmosphere, transition to wing-borne flight is it reentered, and then glide at supersonic speeds to its target. Eventually, two prototypes, designated the A-4b, flew in early 1945, though only one, launched on January 24, could be considered reasonably successful, and even it broke up during the supersonic glide earthwards.[2] Nevertheless, the first technical seed had been planted.

Independent of the Peenemünde group, Dr. Eugen Sänger and Dr. Irene Sänger-Bredt pursued their own similar studies. By 1944 they had completed their elaborate calculations for a manned rocket bomber. The winged-rocket was to have a length of 92 feet, a span of 50 feet, and a takeoff weight of 110 tons. Unlike von Braun, Sänger preferred horizontal launch to a vertical loft. For 11 seconds, a rocket sled would propel the bomber along tracks, two miles in length, until a takeoff velocity of 1,640 feet per second was attained. Under power of its own rocket engine, the vehicle would then climb to an altitude varying from 30 to 60 miles. At the end of ascent, the bomber would proceed in an oscillating, gliding flight, conceivably circumnavigating the Earth.

Sänger was intent on explaining the military value of his proposed system and detailed possible modes of attack. To achieve a strike on a specific point, the vehicle would be accelerated only until it acquired enough velocity to reach the target. After releasing its bomb, the vehicle would turn at the lowest possible speed, ignite its engine, and then return to its original base. For greater distances and bomb loads, the possession of an auxiliary landing site near the target was necessary. If such a site were not available, the rocket bomber would have to be sacrificed. An attack on a larger area, however, did not necessitate a low velocity over the target, and, consequently, there was more likelihood that the bomber could circumnavigate the globe.

The drawbacks to Sänger's proposal were obvious, and, consequently, the German military did not give serious consideration to the rocket bomber. The difficulties inherent in turning the rocket bomber at hypersonic speeds only increased the desirability for an antipodal landing site. To depend on the possibility of possessing friendly landing areas so near a target was unrealistic. Even if a fleet of rocket bombers could circle the Earth, a bomb capacity of about 8,000 pounds per vehicle, as estimated by Sänger, could not have changed the course of conflict.[3]

Soviet military officials obtained copies of Sänger's analysis at the end of the war and became interested in the possibilities of boost-glide flight; Stalin even ordered the kidnapping--if it could be arranged--of the Sänger Bredt team. In 1958, an article which appeared in a Soviet aviation journal referred to a Russian glide-bombing system, capable of attaining an altitude of 295,000 feet and striking a target at a distance of 3,500 nautical miles. While propaganda, it led to an American aviation periodical reporting that Russian scientists were developing an antipodal, glide-missile, designated the T-4A. By March 1960, the Assistant Chief of Staff for Intelligence, USAF headquarters, estimated that the Soviets were at least conducting research directed towards the development of a boost-glide vehicle. Such a system could lead to the development of a craft capable of performing reconnaissance and bombing missions. Air Force intelligence analysts believed that limited flight tests of the manned stage could begin in 1962 and an operational system could be available by 1967. (In any case the first confirmed Soviet work on lifting reentry did not occur until the launch of a subscale lifting body in 1982).[4]

Soon after the war, American military officials also exhibited interest in the possibilities of a boost-glide vehicle. In 1946, the Army Air Force, under a contract with the Douglas Aircraft Company, sheltered a group of American scientists and specialists in various social science areas in an effort to provide analyses and recommendations relating to air warfare. One of the first studies completed under the new Project RAND centered on the design of an orbital vehicle, though of a ballistic; non-lifting design. Basing their analysis on the technological developments of the Peenemünde scientists, RAND experts considered that it was possible, by employing either a four-stage, alcohol-oxygen, or a three-stage, hydrogen-oxygen booster, to place a 500 pound capsule in orbit at an altitude of 300 miles. The initial objective was to provide an orbiting, scientific laboratory, nevertheless, RAND authorities stated that it was feasible to design a capsule with wings for future manned flight.[5] In 1948, RAND made a few more studies investigating the technological difficulties involved in flight beyond the atmosphere; however, the next step was taken by the Bell Aircraft Company.

Dr. von Braun did not become associated with any American efforts in refining the boost-glide concept but, from 1945 through 1950, served as a technical advisor for the Army Ordnance Department at the White Sands Proving Grounds, New Mexico. Dornberger, on the other hand, was held in England for war crimes investigations until 1947 when he became a consultant on guided missiles for the Air Materiel Command at Wright-Patterson Air Force Base, Ohio. In 1950, he left the Air Force and became a consultant for Bell Aircraft. Here, in the fruitful climate of a company that had created the first X-series aircraft, the Nazi missile expert was influential in persuading Bell to undertake a study of boost-glide technology. On April 17, 1952, Bell officials approached Wright Air Development Center (WADC) with a proposal for a manned bomber-missile, abbreviated to Bomi. Bell's glide-vehicle was to be boosted by a two-stage rocket and was to be capable of operating at altitudes above 100,000 feet, at speeds over Mach 4.0, and at a range of 3,000 nautical miles. A month later, Bell submitted a proposal to Wright center for the initiation of a feasibility study. The contractor believed that the study would cost $398,459 and would take 12 months.[6] Bell's work coincided with Wright's interest in the same field, and triggered a receptive review.

By November 28, the Air Research and Development Command (ARDC) headquarters had completed a review of the Bomi project. While Bell's proposal duplicated parts of the Atlas intercontinental ballistic missile and the Feedback satellite reconnaissance programs, command headquarters considered that some phases of Bomi would advance the Air Force's technical knowledge. Consequently, ARDC headquarters requested WADC to evaluate the proposal with the view of utilizing the concept both as a manned bomber and as a reconnaissance vehicle.[7]

Wright center officials completed their evaluation by April 10, 1953 and listed several reasons for not accepting the

Bell proposal. A range of 3,000 nautical miles was too short for intercontinental operations. It was difficult to conceive how the vehicle could be adequately cooled, nor was there sufficient information concerning stability, control, and aeroelasticity at the proposed speeds. Furthermore, Bell's estimated lift-to-drag ratio was far too optimistic. Since it was to operate under an extreme environment, there was also the question of the value of providing a piloted vehicle. Before undertaking such a project, Wright engineers emphasized that the cost and military worth of such a system first had to be established. Center officials added that some doubt existed concerning the ability of the contractor to complete the program successfully.[8]

Bell Aircraft, however, was persistent, and, on September 22, its representatives briefed ARDC headquarters on the Bomi strategic weapon system. Brigadier General F. B. Wood, Deputy Chief of Staff for Development, did think the proposal "somewhat radical" but stated that it could not be considered "outside the realm of possibilities." General Wood then requested WADC to give further consideration to Bell's proposal.[9] Apparently, Wright center officials reconsidered their first evaluation of Bomi, for, in their reply to ARDC headquarters on November 23, they assumed a more favorable position.

Wright engineers considered that the Atlas ballistic missile and the Navaho cruise missile programs offered more promises of successful development than Bomi. The Bell proposal, however, appeared to present a reconnaissance ability far in advance of the Feedback program. Furthermore, Wright officials reasoned that the Bomi vehicle would provide a test craft for several unexplored flight regimes and would offer a guide for the development of manned, hypersonic, military systems. Because of the lack of information, Wright authorities did not recommend the initiation of development but thought that the potential reconnaissance value of

Bomi necessitated a two-year study program. Specifically, Wright officials recommended that Bell be offered a $250,000 contract for one year with the possibility of extending the study for an additional year. This investigation should determine whether the piloted Bomi vehicle was more advantageous than an unmanned version and whether a reconnaissance mission would compromise the strategic striking ability of the system.[10]

ARDC headquarters agreed and approved Wright center's recommendation. Brigadier General L. I. Davis, acting Deputy Chief of Staff for Development, emphasized that the strategic requirements for an intercontinental vehicle, with a range up to 25,000 nautical miles, should be considered. General Davis stated that development of a program such as Bomi would not be undertaken until other contractors could offer competitive concepts. In accordance, the acting deputy chief of staff requested that the Boeing Airplane Company include in its efforts for Project MX-2145 (Design Studies for an Advanced Strategic Weapon System) investigations of a manned, glide-rocket system.[11]

Boeing had undertaken MX-2145 in May 1953 in order to determine the characteristics of a high performance bomber which could succeed the B-58 Hustler and be capable of delivering nuclear weapons over intercontinental ranges by 1960. Later, as directed by ARDC headquarters, Boeing briefly considered the possibility of a manned, reconnaissance glide-rocket. The contractor regarded the method of traveling an intermediate distance and then reversing direction to return to the point of origin as impractical. Rather, Boeing emphasized that it would be more feasible to orbit the Earth. The contractor, however, pointed to the difficulties of devising structures to withstand high temperature and equipment for reconnaissance. Yet, because of the military potential of such a system, the contractor thought that further investigations were indicated.[12]

On April 1, 1954, Wright center completed a contract with the Bell Aircraft Corporation for a design study of an advanced, bomber-reconnaissance weapon system. The contractor was to define the various problem areas and detail the requirements for future programs. Bell had to focus on such problems as the necessity for a manned vehicle, the profiles of possible missions, performance at high temperatures, and the feasibility of various guidance systems.[13]

Bell Aircraft now envisaged a three-stage system, with each stage riding pickaback. This system would total more than 800,000 pounds. Bomi, now designated as MX-2276, would be launched vertically, and the three rocket engines would be fired simultaneously, delivering 1.2 million pounds of thrust. Bell proposed manning the booster stage in order to achieve recovery by use of aerodynamic surfaces. The third-stage would also be piloted and would carry navigation, reconnaissance, and bombardment equipment. Bomi would be capable of reaching an altitude of 259,000 feet, attaining a speed of 22,000 feet per second, and possessing a range of 10,600 nautical miles.

The contractor believed that a piloted system such as Bomi held several advantages over an unmanned version. Reliability of the system would be increased, bombing precision augmented, and reconnaissance information easily recovered. Furthermore, operational flexibility would be enhanced with the possibility of selecting alternate targets. Unmanned instrumentation certainly could not provide for all the necessary contingencies.[14]

With the completion of the initial study in May 1955, the contract expired, but Bell continued its efforts without government funds or direction. On June 1, WADC personnel discussed with the contractor the possibility of officially extending its work. The purpose of the Air Force in considering an extension was to investigate the feasibility of adapting the Bomi concept to Special Reconnaissance System 118P.

On January 4, 1955, ARDC headquarters had issued System Requirement 12, which called for studies of a reconnaissance aircraft or missile possessing a range of 3,000 nautical miles and an operational altitude of more than 100,000 feet. Wright center officials established System 118P, and several contractors investigated the adaptability of boost-glide rockets and vehicles using air-breathing engines to the system requirement. To bring Bell into these efforts, ARDC headquarters gave assurance, in June, that $125,000 would be released for the purpose of extending Bell's Bomi contract, and by September 21, 1955, contract negotiations were completed. Bell's efforts would continue.[15]

At the request of the Assistant Secretary of the Air Force for Research and Development, Trevor Gardner, personnel from the Bombardment Aircraft Division of ARDC headquarters and Bell Aircraft gave several presentations to ARDC and USAF headquarters in November, where the Bomi concept was received with approval.[16*] Meanwhile, officials from the laboratories of Wright center, the laboratories of the National Advisory Committee for Aeronautics (NACA), and the Directorate of Weapon Systems in ARDC headquarters had evaluated the results of the Bomi study and had drawn several conclusions.

Representatives from the three organizations thought that Bell's concept was theoretically practicable and promising, and that the Bomi program should be continued to determine the

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*On August 1, 1955, the management of weapon system development was transferred from the Wright Air Development Center to ARDC headquarters. Detachment One of the Directorate of Systems Management, which included the Bombardment Aircraft Division, however, was located at Wright-Patterson Air Force Base.

feasibility of such a weapon system. Emphasis, however, should be placed on a test program to validate Bell's analysis. The members considered that the most advantageous procedure for Bomi would be a three-step program with the development of a 5,000 nautical mile, a 10,000 nautical mile, and a global system.[17]

By December 1, 1955, Bell had completed its final engineering report for the supplementary contract and had expended a total of $420,000 for the Bomi studies. For System 118P, Bell's design had included a two-stage rocket to boost a vehicle to 165,000 feet at a velocity of Mach 15. The contractor, however, was once again out of funds. Brigadier General H. M. Estes, Jr., Assistant Deputy Commander for Weapon Systems, ARDC headquarters, estimated that about $4 million more would be required for the next 12 to 18 months. General Estes then requested the Deputy Commander for Weapon Systems at ARDC headquarters to allocate $1 million for fiscal year 1956 and to grant authority for the continuation of the program.[18]

While the question of future funding was being debated, officials from the New Development Weapon Systems Office of ARDC headquarters and Bell Aircraft visited Langley Air Force Base, Virginia, in December 1955, to obtain the views of NACA on the Bomi concept. The advisory committee had first become interested in the boost-glide concept when it undertook a preliminary study in 1953 to determine the feasibility of manned, hypersonic flight. On September 30, 1955, Dr. I. H. Abbott, Assistant Director for Research, NACA, thought that more data was required before a development program could be initiated for Bomi. Dr. Abbott hoped that the Air Force would continue to inform NACA on the future progress of the program in order that its laboratories could contribute to the research program. The conference in December resulted in an invitation to NACA for participation in the validation testing for Bomi.[19]

Early in January 1956, the Intelligence and Reconnaissance Division of ARDC headquarters informed the New Development Weapon Systems Office that $800,000 had been allocated for continuation of Bomi. The Air Force, however, considered that the Bell program should now be directed towards the fulfillment of the General Operational Requirement 12, which had been issued on May 12, 1955. This directive called for a piloted, high-altitude, reconnaissance weapon system which was to be available by 1959. Accordingly, the Air Force concluded a contract with Bell on March 20, 1956, totalling $746,500, for Reconnaissance System 459L, commonly known as Brass Bell. In October, the contract was extended to August 31, 1957, bringing total expenditures to approximately $1 million. Later in 1956, Bell was awarded an additional $200,000 and four more months to complete its work.[20]

By December 1956, Bell Aircraft had conceived of a manned, two-stage system which would be propelled over 5,500 nautical miles at a velocity of 18,000 feet per second to an altitude of 170,000 feet by Atlas thrust chambers. With the addition of another stage, Bell engineers reasoned that the range could be extended to 10,000 nautical miles with a maximum speed of 22,000 feet per second.[21]

While the Air Force had channeled Bell's work towards the eventual development of a boost-glide, reconnaissance system, it had not abandoned the application of this concept to the development of a bombardment vehicle. On December 19, 1955, the Air Force had sent a request to the aircraft industry for a study which would incorporate analytical investigations, proposed test programs, and design approaches for a manned, hypersonic, rocket-powered, bombardment and reconnaissance weapon system. Boeing, the Republic Aircraft Company, the McDonnell Aircraft Corporation, the Convair Division of the General Dynamics Corporation, Douglas, and North American Aviation responded to the request. Study contracts, amounting to $860,000 were awarded to the latter three for investigations extending from May through December 1956. Later, the Martin Company, Lockheed Aircraft, and Bell joined in the study. By the end of fiscal year 1957, an additional $3.2 million was expended by Boeing, Convair, North American, Republic, Douglas, and Bell from their own funds.[22]

On June 12, 1956, ARDC headquarters outlined the conditions for the rocket-bomber study, now designated as Robo, in its System Requirement 126. The purpose of the study was to determine the feasibility of a manned, hypersonic, bombardment and reconnaissance system for intercontinental operation by 1965. The main requirement of the proposed system was the ability to circumnavigate the globe and yet operate at a minimum altitude of 100,000 feet. Furthermore, the vehicle would not only have to perform strategic strike missions but, in addition, fulfill a reconnaissance role. The contractors would also have to determine the effects of carrying weapons, ranging in weight from 1,500 to 25,000 pounds, on vehicle design and investigate the feasibility of launching air-to-surface missiles.[23]

The importance of advanced systems such as Brass Bell and Robo was given added emphasis by ARDC commander, Lieutenant General T. S. Power, at his conference on "radical" configurations, held on February 15, 1956. General Power stated that the Air Force should stop considering new and novel configurations and should start developing them. Speeds to any conceivable extent and operation of manned, ballistic rockets beyond the atmosphere should be investigated.[24]

Encouraged by General Power's statement, Major G. D. Colchagoff of the Research and Target Systems Division, ARDC headquarters, considered that one of the promising proposed programs was the manned, glide-rocket, research system. This was to be a vehicle similar to Brass Bell and Robo and would be used to obtain scientific data rather than to fulfill a military role. The research and target division prepared an abbreviated development plan for the test system and submitted it to Air Force headquarters in March. On June 29, headquarters approved the proposal but requested a full development plan.[25] Research and target managers, however, had already encountered funding difficulties.

In April 1956, the research and target division had estimated that $4 million was required for the manned glide-rocket, and a total of $33.7 million was needed for the research-vehicle programs, which included the X-13, the X-14, the XB-47D, the X-15, and a vertical-takeoff-and-landing (VTOL) aircraft. Air Force headquarters, however, had set a ceiling of $8.5 million for all of these programs. The research and target division then undertook negotiations with the Air Materiel Command to determine a method of funding to alleviate this deficiency. If this attempt failed, the division warned USAF headquarters that the Air Force would not have a research-vehicle program.[26]

Air Force headquarters, however, drastically reduced the budget for fiscal year 1957, allocating no funds for the manned glide-rocket. General Power warned that this reduction would postpone his bold research program for at least one year. He cautioned headquarters that this action would seriously jeopardize America's qualitative lead over Russia.[27]

In spite of inadequate funding, ARDC issued System Requirement 131 on November 6, 1956, which requested information from the ARDC director of systems management, Wright center, the flight test center and the Cambridge research center for the preparation of an abbreviated system development plan. The manned, glide-rocket, research program was now titled Hypersonic Weapons Research and Development Supporting System (Hywards) and was classified as System 455L. By December 28, the ARDC Directorate of Systems Plans had completed a development plan for Hywards.[28]

The purpose of the Hywards vehicle was to provide research data on aerodynamic, structural, human factor, and component problems and was to serve as a test craft for development of subsystems to be employed in future boost-glide systems. The research and target division considered three propulsion choices as satisfactory for boosting Hywards. The 35,000 pound thrust chambers, employing fluorine-ammonia fuel, which Bell had under development, was one possibility. The 55,500 and 60,000 pound thrust sustainer engines for the Atlas and Titan systems comprised another. The 50,000 pound thrust XLR-99 engine, employed in the X-15 vehicle, was the third option. One of these rocket systems would propel the Hywards craft to a velocity of 12,000 feet per second and an altitude of 360,000 feet. The initial flight test program was to employ the air-drop technique, similar to the X-15 launch, while later testing would use a rocket-boosted, ground-launch method. The research and target division emphasized that by appropriate modifications to Hywards, increased velocities and orbital flight could be attained to provide continuing test support for the Air Force's technological advances.[29]

On February 27, 1957, the development plans for both Hywards and Brass Bell were presented to USAF headquarters, where it was decided that the two programs were complementary and, therefore, should be consolidated. Funding, however, proved more difficult. For fiscal year 1958, ARDC headquarters had requested $5 million for Hywards and $4.5 million for Brass Bell. Air Force headquarters, however, reduced these requests to a total of $5.5 million. Lieutenant General D. L. Putt, Deputy Chief of Staff for Development, USAF headquarters, hesitated endorsing the boost-glide programs. The lack of Air Force funds necessitated giving priority to the advanced satellite reconnaissance system, 117L, rather than to Hywards or Brass Bell. Furthermore, the X-15 program would provide a more dependable source of research data than the boost-glide programs. Major General R. P. Swofford, Director of Research and Development, USAF headquarters, did recommend that $1 million be allocated for the boost-glide systems, but, on April 30, Air Force headquarters informed ARDC headquarters that the two development plans were disapproved and that a new plan, encompassing all hypersonic weapon systems, should be prepared.[30]

Before the new development plan for Brass Bell and Hywards was completed, additional investigations for the Robo program were accomplished. On June 20, 1957, an ad hoc committee consisting of representatives from ARDC headquarters, Wright Air Development Center, the Cambridge Air Force Research Center, and the Air Materiel Command, was formed to evaluate the Robo studies of the contractors. Advisory personnel from the Strategic Air Command, the National Advisory Committee for Aeronautics, and the Office of Scientific Research were also present.

During the first three days of the conference, the contractors working on System Requirement 126 presented their proposals, most of which centered on the feasibility of manned vehicles. Both Bell and Douglas favored a three-stage, boost-glide vehicle, the former employing fluorine and the latter, an oxygen propellant. The Convair Division also proposed a three-stage system, using fluorine fuel, but its concept differed from the previous two in that a control rocket and turbojet engine were placed in the glider. While North American advanced a two-stage vehicle, using conventional rocket fuel, Republic advocated an unmanned vehicle, powered by a hypersonic cruise, ramjet engine, and boosted by a single-stage rocket. Republic's proposal also involved an unmanned satellite, guidance station, which was to be placed in orbit by a three-stage booster. Finally, Boeing favored an unmanned version and advanced an intercontinental glide-missile. In the opinion of Boeing officials, a manned vehicle would involve a longer development cycle and would not possess any great advantage over a missile.

After the presentation of the contractor's proposals, the committee spent the next two days evaluating the concepts. While Wright officials thought that the boost-glide concept was feasible and would offer the promise of an operational weapon system by 1970, they also pointed to several problems confronting the Air Force. The details of configuration design were yet unknown. The status of research in the area of materials was not sufficiently advanced. Lack of hypersonic test facilities would delay ramjet development until 1962. Rocket engines were not reliable enough to allow an adequate safety factor for manned vehicles during launch. Finally, center officials pointed to the difficulty of providing a suitable physiological environment for a piloted craft.

Officials of the Cambridge Research Center focused on a different set of problems. All the proposals employed an inertial, autonavigating system, and Cambridge officials pointed out that these systems required detailed gravitational and geodetical information in order to strike a target accurately. The effect of the Earth's rotational motion became extremely important at hypersonic speeds, and, consequently, this factor would have to be considered in determining the accuracy of the guidance systems. Research center scientists also emphasized that an ion sheath would be created as the vehicle penetrated the atmosphere during reentry; this phenomenon would hinder communication. There were other difficulties that required investigation. The thermal properties of the atmosphere would have to be studied in order to determine the extent of aerodynamic heating. Adequate data on the effect of wind turbulence and the impact of meteor dust on the vehicle would have to be determined. Officials of the Cambridge center added one more problem: the presence of ionization trails, infrared radiation, and vehicle contrails could facilitate hostile detection of the vehicle.

It was apparent to the representatives of the Air Materiel Command that the development of either a manned or unmanned system would be feasible only with increased and coordinated efforts of six to eight years of basic research. More detailed knowledge was required of the system design in order that a determination could be made of various logistical problems and the complexity of the launching area. Viewing the development costs for the ballistic missile programs, materiel officials estimated that the cost for Robo would be extremely high. In order that the Robo program could be continued, air materiel officials recommended that the participating contractors be given specific research projects. A contracting source for the conceptual vehicle should then be chosen, and, after approximately six years, competition for the weapon system development should be held.

After surveying the contractors' proposals and the analyses of Wright center, the materiel command, and the Cambridge center, the ad hoc committee concluded that a boost-glide weapon system was technically feasible, in spite of the numerous problems inherent in the development of such a system. With moderate funding, an experimental vehicle could be tested in 1965, a glide-missile in 1968, and Robo in 1974. The committee emphasized that the promise of boost-glide vehicles to be employed either for scientific research or as weapon systems was necessity enough for the undertaking. The members of the committee went beyond the scope of the Robo proposals and recommended that ARDC headquarters submit a preliminary development plan to USAF headquarters, covering the entire complex of boost-glide vehicles.[31]

By October 10, 1957, the Director of Systems Plans, ARDC headquarters, had completed consolidating the details of the Hywards, Brass Bell, and Robo programs into a three-step, abbreviated, development plan for the new Dyna-Soar (a compound of dynamic soaring) program. Like Hywards, the first phase of System 464L involved the development of a manned, hypersonic, test vehicle which would obtain data in a flight regime significantly beyond the reach of the X-15 and would provide a means to evaluate military subsystems. To avoid further confusion between the purpose of Dyna-Soar and the X-15 vehicle, the directorate made a clear distinction between a research vehicle and a conceptual test vehicle. Both vehicles were designed to obtain flight data in a regime which had not been sufficiently well defined; however, the latter was to obtain information for the development of a specific system. The initial objectives of the Step I vehicle would be a speed of approximately 18,000 feet per second and altitudes of 350,000 feet and would be attained by use of one of the three engines considered for Hywards.

The Brass Bell program assumed the position of Step II in the Dyna-Soar plan. A two-stage rocket booster would propel the reconnaissance vehicle to a speed of 18,000 feet per second and an altitude of about 170,000 feet. The vehicle would then glide over a range of 5,000 nautical miles. The system would have to be capable of providing high quality photographic, radar, and intelligence information. The vehicle would also have to possess the ability of performing strategic bombing missions. The Director of Systems Plans considered that the liquid rocket Titan sustainer appeared usable; however, investigations under Step I could prove the fluorine engine more valuable.

Step III incorporated the Robo plans, and encompassed a more sophisticated vehicle which would be boosted to 300,000 feet and 25,000 feet per second and would be capable of orbital flight. Like the earlier phase, this vehicle would be able to execute bombardment or reconnaissance missions.

Because of insufficient data, the directorate reasoned that the Dyna-Soar program could not be immediately initiated. A two-phase program for preliminary investigations had to come first. Phase one would involve validation of various assumptions, theory, and data gathered from previous boost-glide studies, provide design data, and determine the optimum flight profile for the conceptual vehicle. The second part would refine vehicle design, establish performance, and define subsystems and research instrumentation. While this two-phase preliminary program would consume 12 to 18 months, preliminary studies for the Brass Bell and Robo phases of Dyna-Soar could be started. Following this procedure, flight testing at near satellite speeds for the conceptual test vehicle would begin in 1966. The estimated operational date for Dyna-Soar II was set in 1969, and for Dyna-Soar III in 1974.

The Director of Systems Plans argued that the hypersonic, boost-glide vehicle offered a considerable extension of speed, range, and altitude over conventional Air Force systems. Furthermore, this concept represented a major step towards manned space flight. It could not be safely assumed, the systems plans directorate reasoned, that the intercontinental ballistic missile would destroy all the required targets in the decade of the 1970s. Difficulties in penetrating hostile territory by air-breathing vehicles further enhanced the necessity for a manned, boost-glide vehicle. Additionally, the proposed reconnaissance ability of Dyna-Soar could provide more detailed and accurate intelligence data than other Air Force reconnaissance systems then under development. The director warned that time could not be economically bought. If the boost-glide weapon system were necessary, it was imperative to initiate the Dyna-Soar program by allowing a funding level of $3 million for fiscal year 1958.[32]

On October 17, 1957, Lieutenant Colonel C. G. Strathy of the Research and Target Systems Division presented the Dyna-Soar plan to Air Force headquarters. Brigadier General D. Z. Zimmerman, Deputy Director of Development Planning, USAF headquarters, gave enthusiastic endorsement but thought that ARDC headquarters should take a more courageous approach. Command headquarters, he stated, should immediately consider what could be accomplished with greater funding than had been requested. Also present at the briefing was Dr. J. W. Crowley, Associate Director for Research of NACA. He pointed out that the national advisory committee was strongly in favor of initiating the conceptual vehicle program as a logical extension of the X-15 program. He emphasized that his organization was directing its research towards the refinement of the boost-glide concept and was planning new facilities for future research.[33]

Brigadier General H. A. Boushey, Deputy Director of Research and Development, USAF headquarters, informed ARDC headquarters, on November 15, that the Dyna-Soar abbreviated development plan had been approved. General Boushey's office then issued, on November 25, Development Directive 94, which allocated $3 million of fiscal year 1958 funds for the hypersonic, glide-rocket weapon system. The boost-glide concept offered the promise of a rapid extension of the manned flight regime, and following General Zimmerman's reasoning, the deputy director stated that the philosophy of minimum risk and minimum rate of expenditure must be abandoned. If the concept appeared feasible after expenditure of fiscal year 1958 and 1959 funds, the boost-glide program should definitely be accelerated. Not certain of the feasibility of piloted flight, Air Force headquarters directed that the study of manned and unmanned reconnaissance and bombardment weapon systems should be pursued with equal determination. A decision on whether the vehicle was to be piloted would be made in the future and based on substantial analysis. Finally, USAF headquarters stressed that the only objective of the conceptual test vehicle was to obtain data on the boost-glide flight regime. Early and clear test results from this system must be obtained.[34] Thus, by the end of 1957, the Air Force had advanced the field of hypersonic boost-glide studies towards a clearly delineated development program for an orbital, military vehicle--Dyna-Soar.

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24. Memo., Maj. G. D. Colchagoff, Res. & Target Sys. Div., Dep. Cmdr/Weap. Sys., Hqs. ARDC to Lt. Col. R. C. Anderson, Res. & Target Sys. Div., 16 Feb. 1956, subj.: New Research Systems.

25. Ibid.; Uyehara, Antecedents, p. 51.

26. Memo., Res. & Target Sys. Div., Hqs. ARDC, 16 Apr. 1956, subj.: Research Vehicle Program.

27. Ltr., Lt. Gen. T. S. Powers, Cmdr., ARDC to Hqs. USAF, 16 July.

28. SR 131, Hqs. ARDC, 6 Nov. 1956; Chronology, DSM, Hqs. ARDC, 14 Mar. 1959, subj.: Significant Events, Dyna-Soar Background, p. 15.

29. R&D Proj. Card, System 455L, Res. & Target Sys. Div., Hqs. ARDC, 28 Dec. 1956, subj.: Hypersonic Glide Rocket Research System.

30. Uyehara, Antecedents, pp. 55-56, 57.

31. Rpt., Ad Hoc Committee, 1 Aug. 1957, subj.: Evaluation Report of the Ad Hoc Committee for ARDC System Requirement Number 126, Robo; rpt., Ad Hoc Committee, 1 Oct. 1957, subj.: Supplement 1 to the Evaluation Report.

32. Abbreviated System Development Plan, System 464L, Hqs. ARDC, 10 Oct. 1957, subj.: Hypersonic Strategic Weapon System.

33. Trip rpt., Lt. W. C. Walter, New Dev. Weap. Sys. Ofc., Hqs. ARDC to R. D. Hodge, Ch., New Dev. Weap. Sys. Ofc., 21 Oct. 1957, subj.: Visit to Hqs. USAF on Project Dyna-Soar; ltr., Brig. Gen. H. A. Boushey, Dep. Dir., Res. & Dev., DCS/Dev., Hqs. USAF to Cmdr., ARDC, 15 Nov. 1957, subj.: Approval of Abbreviated Development Plan for System 464L.

34. DD 94, Hqs. USAF, 25 Nov. 1957, subj.: Hypersonic Glide Rocket Weapon System.

CHAPTER II

SYSTEM 464L

With the approval of the abbreviated development plan, the direction of the Dyna-Soar program appeared clearly marked. An experimental glider, a reconnaissance vehicle, and a bombardment system comprised a three-step progression. During the existence of System 464L, however, officials in the Department of Defense subjected the program to severe criticism. The necessity of orbital flight and the feasibility of a boost-glide weapon system were points frequently questioned. By November 1959, the project office had to undertake an exacting investigation of the Dyna-Soar approach to manned space flight. Certainty of program objectives had momentarily disappeared.

On December 21, 1957, ARDC headquarters issued System Development Directive 464L, which stipulated that the mission of the conceptual test vehicle, Dyna-Soar I, was to obtain data on the boost-glide flight regime in support of future weapon system development. Headquarters suggested that a system development plan for Dyna-Soar I and the recommended weapon system programs be completed on October 31, 1958 and set July 1962 as the date for the first flight of the conceptual test vehicle. Finally, ARDC headquarters approved immediate initiation of the program by directing the source selection process to begin.[1]

By January 25, 1958, a task group of the source selection board had screened a list of 111 contractors to determine potential bidders for the Phase I design. The working group considered that Bell, Boeing, Chance-Vought Aircraft, Convair, General Electric Company, Douglas, Lockheed, Martin, North American, and Western

Electric Company would be able to carry out the development. Later, the list was amended to include McDonnell Aircraft, Northrop Aircraft, and Republic Aviation.[2]

The source selection board had received, by March 1958, proposals from nine contractor teams. Essentially, two approaches were taken in considering the development of Dyna-Soar I. In the satelloid concept, a glider would be boosted to an orbital velocity of 25,500 feet per second to an altitude of 400,000 feet, thereby achieving global range as a satellite. In the flexible boost-glide proposal, however, the projected vehicle would follow a glide-trajectory after expenditure of the booster. With a high lift-to-drag ratio at a velocity of 25,000 feet per second and an altitude of 300,000 feet, the glider could circumnavigate the Earth.

Three contractors offered the first approach, the satelloid concept, as the most feasible. Republic conceived of a 16,000 pound delta-wing glider boosted by three solid propellant stages. The vehicle, along with a 6,450 pound space-to-earth missile, would be propelled to a velocity of 25,700 feet per second and an altitude of 400,000 feet. Lockheed considered a 5,000 pound glider similar in design to that of Republic. This vehicle could operate as a satelloid, however, the contractor suggested a modified Atlas booster which lacked sufficient thrust for global range. A 15,000 pound vehicle similar to the X-15 craft comprised the proposal of North American. The booster was to consist of a one-and-a-half stage liquid propellant unit with an additional stage in the glider. Operated by a two-man crew, the vehicle was also to have two small liquid engines for maneuvering and landing. The glider was to be propelled to a velocity of 25,600 feet per second and an altitude of 400,000 feet and would operate as a satelloid.

Six contractors concentrated on the flexible boost-glide concept. Douglas considered a 13,000 pound arrow-wing glider which was to be boosted by three modified solid propellant stages of the Minuteman system. An additional stage would provide a booster for advanced versions of Dyna-Soar. McDonnell offered a design similar to that of Douglas but proposed, instead, the employment of a modified Atlas unit. A delta-wing glider, weighing 11,300 pounds, was recommended by Convair. This contractor did not consider the various possibilities for the booster system but did incorporate a turbojet engine to facilitate landing maneuvers. Martin and Bell joined to propose a two-man delta-wing vehicle weighing 13,300 pounds, which would be propelled by a modified Titan engine. Employing Minuteman solid propellant units, Boeing offered a smaller glider, weighing 6,500 pounds. Finally, Northrop proposed a 14,200 pound delta-wing glider which was to be boosted by a combination liquid and solid propellant engine.

The task group of the source selection board, after reviewing the proposals, pointed out that with the exception of the North American vehicle all of the contractors' proposed configurations were based on a delta-wing design. The size of the proposed vehicles was also small in comparison with current fighter aircraft such as the F-106. McDonnell and Republic offered vehicles which could carry the biggest payload, yet they in turn required the largest boosters. At the other extreme was Boeing's proposal which could carry only 500 pounds, including the weight of the pilot. The task group also emphasized that of the three contractors proposing the satelloid concept Lockheed's vehicle fell short of a global range. Of the six contractors offering the flexible boost-glide approach, only the Martin-Bell team and Boeing proposed a first-step vehicle capable of achieving orbital velocities. The other four considered a global range in advanced versions.[3]

By the beginning of April, the working group had completed its evaluation of the contractors' proposals, and, on June 16, 1958, Air Force headquarters announced that the Martin Company and the

Boeing Airplane Company both had been selected for the development of Dyna-Soar I.[4] Major General R. P. Swofford, Jr., then Acting Deputy Chief of Staff for Development, USAF headquarters, clarified the selection of two contractors. A competitive period between Martin and Boeing would extend from 12 to 18 months at which time selection of a single contractor would be made. General Swofford anticipated that $3 million would be available from fiscal year 1958 funds and $15 million would be set for 1959. The decision as to whether Dyna-Soar I would operate as a boost-glide or a satelloid system was left open, as well as the determination of a piloted or unmanned system. The acting deputy directed that both contractors should proceed as far as possible with available funds towards the completion of an experimental test vehicle. The design, however, should approximate the configuration of a Dyna-Soar weapon system.[5]

Apparently some questioning concerning the validity of the Dyna-Soar program occurred at Air Force headquarters, for, on July 11, Major General J. W. Sessums, Jr., Vice Commander of ARDC, stated to Lieutenant General R. C. Wilson, USAF Deputy Chief of Staff for Development, that Air Staff personnel should stop doubting the necessity for Dyna-Soar. Once a new project had been sanctioned by headquarters, General Sessums considered, support should be given for its completion.[6] In reply, General Wilson assured General Sessums that the Air Staff held the conviction that Dyna-Soar was an important project. However, due to the interest of the Advanced Research Projects Agency (ARPA) and the National Aeronautics and Space Administration (NASA) and their undetermined responsibilities in the development of systems such as Dyna-Soar, the Air Force firmly had to defend its projects to the Department of Defense.[7]* General Wilson closed by reassuring General Sessums of his full endorsement of the Dyna-Soar program.[8]

While the Dyna-Soar program had the verbal support of USAF headquarters, Lieutenant General S. E. Anderson, ARDC commander, considered that the program required additional funds. He reminded General Wilson that ARDC headquarters, with the efforts of only one contractor in mind, had requested $32.5 million for fiscal year 1959. The Air Staff had limited this amount to $15 million for the contributions of both Boeing and Martin. Consequently, $52 million was now required for the 1959 Dyna-Soar program. The ARDC commander emphasized that if System 464L were to represent a major step in manned space flight, then the delay inherent in the reduced funding must be recognized and accepted by Air Force headquarters.[9] General Wilson agreed with General Anderson's estimation and stated that the approved funding level for fiscal year 1959 would undoubtedly delay the program by one year. The stipulated $18 million for both fiscal years 1958 and 1959, although a minimum amount, would permit the final contractor selection. General Wilson did assure the ARDC commander that the

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*Previously, considerable discussion within the Air Force had taken place concerning the role which the National Aeronautics and Space Administration, earlier designated the National Advisory Committee for Aeronautics, was going to play in the Dyna-Soar program. On January 31, 1958, Lieutenant General D. L. Putt, Deputy Chief of Staff for Development, USAF headquarters, asked NACA to join with the Air Force in developing a manned, orbiting, research vehicle. He further stated that the program should be managed and funded along the lines of the X-15 program. It appeared that General Putt was proposing a Dyna-Soar I program under the direction of NACA. ARDC headquarters strongly recommended against this contingency on the grounds that Dyna-Soar would eventually be directed towards a weapon system development. By May 20, General T. D. White, Air Force Chief of Staff, and Dr. H. L. Dryden, NACA director, signed an agreement for NACA participation in System 464L. With the technical advice and assistance of NACA, the Air Force would direct and fund Dyna-Soar development. On November 14, 1958, the Air Force and NASA reaffirmed this agreement.

Air Staff would try to alleviate the situation and thought there was a possibility for increasing fiscal year 1959 funding.[10]

Major General V. R. Haugen, Assistant Deputy Commander for Weapon Systems, Detachment One, made another plea to the Deputy Chief of Staff for Development. He estimated that inadequate funding would push the flight date for the research vehicle back by eight months. Such austerity would hinder the developmental test program and cause excessive design modification. General Haugen strongly urged the augmentation of fiscal year 1959 funding to $52 million. Besides this, it was important that the full release of the planned $15 million be immediately made.[11]

On September 4, Colonel J. L. Martin, Jr., Acting Director of Advanced Technology, USAF headquarters, offered additional clarification of the funding situation to Detachment One. He stated that the two separate efforts by Boeing and Martin should only be maintained until study results pointed to a single, superior approach. It was possible for this effort to be terminated within 12 months. Colonel Martin pointed out that the Air Staff was aware that the $18 million level would cause delays; these funds, however, would provide the necessary information for contractor selection. He did announce that release of the $15 million had been made. Lastly, Colonel Martin directed that the term "conceptual test vehicle" would no longer be used to refer to Dyna-Soar I and, in its place, suggested the words "experimental prototype."[12]

The Dyna-Soar project office replied that the competitive period could be terminated by April instead of July 1959; however, additional funding could be effectively utilized.[13] These efforts to increase the Dyna-Soar allotment had no effect, for, on September 30, 1958, USAF headquarters now informed Detachment One that the $10 million procurement funds for fiscal year 1959 had been canceled. All that remained for development of Dyna-Soar was

$3 million from fiscal year 1958, with $5 million for 1959. In his August 12 letter to General Anderson, General Wilson mentioned the possibility of increased funding for fiscal year 1959. Apparently a figure of $14.5 million was being considered; however, Air Force headquarters also informed ARDC that this proposed increase would not be made. Headquarters further directed that expenditure rates by the contractors be adjusted in order that the $8 million would prolong their efforts through January 1, 1959.[14]

From October 20 through 24, 1958, Mr. W. E. Lamar, in the Deputy for Research Vehicles and Advanced Systems, and Lieutenant Colonel R. M. Herrington, Jr., chief of the Dyna-Soar project office, briefed Air Force headquarters on the necessity of releasing funds for the Dyna-Soar program. The discussions resulted in several conclusions. The objectives of the program would remain unchanged, but further justification would have to be given to Department of Defense officials. The position of NASA in the program was reaffirmed, and it was further stipulated that ARPA would participate in system studies relating to Dyna-Soar.[15] These decisions, however, did not offer immediate hope for increased funding.

Early in November 1958, Colonel Herrington and Mr. Lamar briefed officials of both ARDC and USAF headquarters on the question of Dyna-Soar funding. General Anderson, after hearing the presentation, stated that he supported the program but thought that references to space operation should be deleted in the presentations to the Air Staff. Later, during a briefing to General Wilson, USAF officials decided that suborbital aspects and possibilities of a military prototype system should be emphasized. With the sanction of the Air Force Vice Chief of Staff, General C. E. LeMay, the Dyna-Soar presentation was given to Mr. R. C. Horner, the Air Force Assistant Secretary for Research and Development. The latter emphasized that if a strong weapon system program were offered to Department of Defense officials, Dyna-Soar would probably be terminated. Rather, Secretary Horner suggested that the program be slanted towards the development of a military research system. He stated that a memorandum would be sent to the defense secretary requesting release of additional funds for Dyna-Soar.[16] While Colonel Herrington and Mr. Lamar achieved their funding objectives, it was also apparent that the final goal of the Dyna-Soar program--the development of an operational weapon system--was somewhat in jeopardy.

In accordance with ARDC System Development Directive 464L, the Dyna-Soar project office had completed, in November, a preliminary development plan which supplanted the abbreviated plan of October 1957. Instead of the three-step approach, the Dyna-Soar program would follow a two-phase development. Since the military test vehicle would be exploring a flight regime which was significantly more severe than that of existing Air Force systems, the first phase would involve a vehicle whose function was to evaluate aerodynamic characteristics, pilot performance, and subsystem operation. Dyna-Soar I was to be a manned glider with a highly-swept, triangular-planform wing, weighing between 7,000 and 13,000 pounds. A combination of Minuteman solid rockets could lift the vehicle, at a weight of 10,000 pounds, to a velocity of 25,000 feet per second and an altitude of 300,000 feet. By employing a liquid rocket such as the Titan system, a 13,000 pound vehicle could be propelled to a similar speed and height. The project office stipulated that a retro-rocket system to decelerate the glider and an engine to provide maneuverability for landing procedures would be necessary.

Assuming a March 1959 approval for the preliminary development plan, the Dyna-Soar office reasoned that the air-drop tests could begin in January 1962, the suborbital, manned, ground-launch tests in July 1962, and the first, piloted, global flight in

October 1963. While this first phase was under development, weapon system studies would be conducted concurrently, with the earliest operational date for a weapon system set for 1967. This Dyna-Soar weapon could perform reconnaissance, air defense, space defense, and strategic bombardment missions.[17] The problem of obtaining funds to continue the program, not an outline of Dyna-Soar objectives, was still, however, of immediate importance.

On December 4, 1958, the Secretary of the Air Force requested the Secretary of Defense to release $10 million for the Dyna-Soar program. Apparently the defense department did not act immediately, for, on December 30, Air Force headquarters informed Detachment One that release of these funds could not be expected until January 1959.[18] The project office urgently requested that procurement authorizations be immediately issued.[19] Finally, on January 7, the Deputy Secretary of Defense, D. A. Quarles, issued a memorandum to the Secretary of the Air Force, which approved the release of $10 million for the Dyna-Soar program. The deputy secretary emphasized that this was only an approval for a research and development project and did not constitute recognition of Dyna-Soar as a weapon system. The stipulated increase of $14.5 million was not to be released until a decision was made concerning the Boeing-Martin competition.[20]

Air Force headquarters, on January 14, 1959, requested the Dyna-Soar office to provide a detailed program schedule. Concerning the Dyna-Soar I military test system, planning should be based on the following projected funding: $3 million for fiscal year 1958, $29.5 million for 1959, and $35 million for 1960. Headquarters further directed that the competitive period for the contractors would end by April 1 with a final selection announced by July 1, 1959. While emphasis on a weapon system would be minimized, joint Air Force and ARPA weapon system studies would proceed under separate agreement with Dyna-Soar contractors. The project office was also directed to consider two other developmental approaches. The first would assume that Dyna-Soar objectives had definitely been changed to center on a research vehicle, similar to the X-15 craft, and planning would be based on a projected funding of $78 million for fiscal year 1961, $80 million for 1962, $80 million for 1963, and $40 million for 1964. In the second approach, the Dyna-Soar program would include weapon system objectives, and a funding total of $650 million extending from fiscal year 1961 through 1967 would be assumed. The next day, Air Force headquarters partially revised its directions by stipulating that the source selection process should be completed by May 1, 1959.[21]

On February 6, 1959, the Dyna-Soar project office pointed out that the May 1 date was impracticable, but the office did anticipate a presentation on source selection to the Air Council by June 1. The project office went on to emphasize that the funding forecasts were incompatible with the flight dates which had been specified to the contractors. It was apparent to the project office that only heavy expenditures during the beginning of phase two could result in the questioned flight dates. The Dyna-Soar office, consequently, requested Air Force headquarters to provide a more realistic funding schedule.[22]

In mid-February, the Dyna-Soar office further clarified its position. The approval of only $5 million in development funds for fiscal year 1959 (the release of $10 million had been for procurement), instead of a revised request of $28 million, had a serious effect on the program by reducing the applied research and development program. Furthermore, the project office had originally requested $187 million for fiscal year 1960, an estimate that was predicted on more extensive effort during fiscal year 1959 than was actually taking place under the reduced funding level. Air Force headquarters had only projected $35 million for fiscal year 1960. The result would be a prolongation of the program.[23] This statement of the project office had some impact on headquarters, for, on February 17, the Air Staff requested the project office provide additional information on the program based on fiscal year 1960 funding levels of either $50 million or $70 million.[24]

The depreciation of Dyna-Soar as a weapon system by the defense department, as exemplified by the Secretary Quarles' memorandum of January 7, did not alter the necessity, in the opinion of the Air Force, for a boost-glide weapon. On February 17, 1959, Air Force headquarters revised its General Operation Requirement 92, previously issued on May 12, 1955. Instead of referring to a high-altitude reconnaissance system, the Air Force now concentrated on a bombardment system. USAF headquarters stated that this system, capable of target destruction, was expected to operate at the fastest attainable hypersonic speed, within and above the stratosphere, and could complete at least one circumnavigation of the Earth. This projected system would be capable of operation from 1966 to 1970.[25]

On April 13, 1959, Dr. H. F. York, Director of Defense for Research and Engineering, firmly established the objectives for Dyna-Soar I. The primary goal was the non-orbital exploration of hypersonic flight up to a velocity of 22,000 feet per second. Launched by a booster already in production or planned for the national ballistic missile and space programs, the vehicle would be manned, maneuverable, and capable of controlled landings. Secondary objectives were the testing of military subsystems and the attainment of orbital velocities. The Department of Defense instructed that the accomplishment of these last objectives should only be implemented if there were no adverse effects on the primary objective. The additional $14.5 million was now authorized for fiscal year 1959, giving a total of $29.5 million for that year.

The Department of Defense inquired whether this figure plus a proposed $35 million for fiscal year 1960 would be sufficient to carry out the program. If the Air Force did not consider this feasible, then an alternate program should be submitted for review.[26]

Command headquarters was not in accord with these directions. In an effort to fulfill the conditions established by General Operational Requirement 92, the research and development command issued, on May 7, 1959, ARDC System Requirement 201. The Dyna-Soar I vehicle was to be a military test system developed under the direction of the Air Force with technical assistance from the National Aeronautics and Space Administration. The purpose of this system would be to determine the military potential of a boost-glide weapon system and provide research data on flight characteristics up to and including global flight. Concurrently, studies would be made concerning a weapon system based on this type of hypersonic vehicle. Headquarters then directed its Detachment One to prepare a development plan for Dyna-Soar by November 1, 1959.[27*]

Major General Haugen, in reply to the directions of Dr. York, "strongly recommended" that the attainment of orbital velocities and the testing of military subsystems should be a primary, not a secondary objective. He further stated that Dyna-Soar was the only manned vehicle program which could determine the military potential in the near-space regime. It was "extremely important," the systems management director stated, that the accomplishment of the Dyna-Soar mission not be compromised by restrictions which limited safety, reliability, and growth potential in deference to short-term monetary savings.[28]

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*By January 1959, the preliminary development plan of November 1958 had been forwarded to ARDC and USAF headquarters, however, apparently neither headquarters gave it official sanction.

General Haugen's organization then drew up a position paper substantiating these recommendations. The directorate firmly believed that both the primary and secondary objectives had to be achieved. Concentration on the first set of objectives would prevent investigation of reentry from orbit and the adequate testing of military subsystems. The directorate then recommended a program involving the fabrication of eight unmanned vehicles, eight manned vehicles, and 27 boosters, all to be employed in a total of 25 launchings. This would cost a total of $665 million. While modification of this program to conform with only the primary objectives would reduce the cost by $110 million, it would seriously lessen the possibility of evolving a weapon system from Dyna-Soar I.[29]

Excluding $18 million expended during contract competition, the Deputy Chief of Staff for Development in Air Force headquarters established, on May 28, $665 million as the maximum total of the Dyna-Soar program. For planning purposes $77 million was set for fiscal year 1960.[30] On June 11, 1959, the Air Force Council considered this last figure to be excessive, and the deputy chief of staff had to recant: $35 million was to be used in place of the $77 million.[31]

During a briefing on June 23, 1959, officials of the project office and Dr. J. V. Charyk, Assistant Secretary of the Air Force for Research and Development, further discussed the questions of Dyna-Soar funding and objectives. Apparently, Dr. Charyk, at this point, was not in full agreement with Dr. York's position. The assistant secretary considered that the overall purpose of the program was to exploit the potentialities of boost-glide technology, and, consequently, he implied that orbital velocities should be attained early in the program. For fiscal year 1960, he favored $77 million instead of $35 million but raised the question of how much a total funding level of $300 million to $500 million would compromise the program.* Dr. Charyk then reported to the project officials that Dr. York appeared quite concerned over the effort necessary for modification of a proposed Dyna-Soar booster.[32]

The Air Force source selection board had already appraised the Boeing and Martin proposals. Although both contractors offered similar delta-wing designs, they differed in their selection of boosters. While Boeing only considered an orbital Atlas-Centaur combination, Martin officials offered a suborbital Titan A (later renamed the Titan I) and an orbital Titan C. The board deemed the Boeing glider superior but also recommended use of Martin's orbital booster. The Secretary of the Air Force, J. H. Douglas, did not agree. Development of a new booster, capable of orbital velocities, was clearly not in accord with Dr. York's direction. The secretary recommended further study of the configuration and size of the vehicle to determine whether the glider could be modified to permit compatibility with a basic, suborbital, Titan system. Furthermore, Secretary Douglas was concerned about the total cost of the program. He did not think that funding should be increased by attempting to configure a vehicle which conformed to an anticipated weapon system. Consequently, the Secretary of the Air Force directed a reassessment of the Dyna-Soar program, with the ultimate objective of reducing the overall expense. Accordingly, USAF headquarters directed Detachment One to examine the possibilities for a lighter vehicle and to analyze a development program based on a total cost of not more than $500 million.[33]

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*The documentary source, as cited in reference 32, for Dr. Charyk's comments referred to the $77 million and $35 million as projected figures for fiscal year 1959. Placed in context of the funding discussions concerning the Dyna-Soar program, these estimates obviously applied to fiscal year 1960 and not 1959.

Designation of the booster, management of booster development and procurement, and most important, the purpose of the program, were problems that became intertwined in the series of discussions following Secretary Douglas' instructions. After a July 14 meeting with Dr. Charyk, General Boushey, Colonel W. L. Moore, Jr., and Lieutenant Colonel Ferer, General Haugen directed systems management to prepare a presentation designed to answer the questions raised by Secretary Douglas and also to outline the participation of the Ballistic Missiles Division (BMD) in the Dyna-Soar program.* After reviewing this briefing on July 22, 1959, Lieutenant General B. A. Schriever, now ARDC commander, instructed General Haugen's directorate to prepare a detailed management plan for booster development.[34]** Dr. York, however, on July 27, placed a new complication in this planning effort by requesting the Air Force secretary and the director of ARPA to investigate the possibility of a common development of a Dyna-Soar booster and a second stage for the Saturn booster of NASA. The Director of Defense for Research and Engineering stated that no commitments for the propulsion system would be made until this proposal had been considered. Dr. York apparently had in mind reviving consideration of the Titan C for System 464L and modifying this booster for use in the Saturn program.[35]

On July 28 and 29, General Haugen and Brigadier General O. J. Ritland, BMD commander, completed a tentative agreement concerning the management of Dyna-Soar booster development. During a series of meetings on August 11 and 13, however, General Schriever and General Anderson, AMC commander, could not

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*Colonel Moore succeeded Colonel R. M. Herrington, Jr., as chief of the Dyna-Soar Weapon System Project Office early in July 1959.

**On March 10, 1959, Lieutenant General S. E. Anderson, previously ARDC commander, became commander of the Air Materiel Command. Lieutenant General B. A. Schriever, on April 25, 1959, assumed command of ARDC.

agree on a method of booster procurement. With the exception of the parts pertaining to BMD participation in the Dyna-Soar program, Mr. Lamar then gave the Dyna-Soar presentation to Dr. Charyk, with Generals Wilson, Ferguson, and Haugen attending. After preliminary data was given on Titan C and the Saturn second stage, Dr. Charyk was asked to recommend to the defense department that a contractor source selection be made for Dyna-Soar. He declined: subcontractor selection had not been adequately competitive and the proposed Dyna-Soar funding was too high.[36]

By the middle of August, the Ballistic Missiles Division had completed its evaluation of possible Dyna-Soar boosters. Largely because of serious stability and control problems, an Atlas-Centaur combination was rejected in favor of the Titan C. Concerning Dr. York's proposal, west coast officials believed that it was impractical to employ a precisely identical booster stage for both the Dyna-Soar and Saturn projects. Since Titan C was essentially a cluster of four LR87-AJ-3 engines, ballistic division engineers did recommend employing two of these propulsive units as a Saturn second stage.[37] Discussions between Dr. Charyk, Dr. York, and ballistic division officials concerning selection of the Dyna-Soar booster followed. Finally, while a booster was not designated, Dr. Charyk, Generals Wilson, Ferguson, and Boushey decided, on September 25, that Titan C would not be employed in the program.[38]

On September 23, Lieutenant General W. F. McKee, AMC vice commander, took up the question of booster procurement and proposed to General Schriever a management plan, based on discussions between ARDC and AMC personnel, for the Dyna-Soar program. Because of the wide participation of government agencies and industry, control of Dyna-Soar had to be centralized in a specific organization. While the system was to be procured under two contracts, one for the glider and one for the propulsion unit, the contractor responsible for the manufacture of the vehicle would be given responsibility for integration of the entire system and would act as weapon system contractor. Overall management would be vested in a joint ARDC and AMC project office located at Wright-Patterson Air Force Base. Concerning the procurement authority of the Aeronautical Systems Center (ASC) and the Ballistic Missiles Center (BMC), both of the materiel command, General McKee suggested that the aeronautical center negotiate the two contracts, utilizing the experience available at the ballistic center. The Aeronautical Systems Center, however, would delegate authority to the ballistic center to contractually cover engineering changes. This delegation would be limited to actions not affecting overall cost, compatibility between booster and vehicle, and system performance. General McKee closed by recommending that ARDC and AMC forward a message to Air Force headquarters outlining this proposal.[39]

General Schriever, on October 2, informed AMC officials that he agreed with General McKee's proposed message to USAF headquarters. He did wish to point out, however, that the plan did not adequately reflect the increased role that ARDC agencies at Wright Field were intending to play. General Schriever further stated that ARDC was going to establish a single agency for all booster research and development which would incorporate the use of BMD and BMC.[40] General Anderson replied that he did not understand the ARDC commander's statement concerning increased management responsibility of Wright agencies. He stated that the AMC plan stressed this aspect. General Anderson further emphasized that the materiel command recognized BMD's technical responsibility for the Dyna-Soar booster and had agreed to delegate necessary procurement authority. The AMC commander did not think it was necessary, however, to delegate authority to negotiate contracts. This authority, along with overall technical management, should rest in the ARDC and ASC weapon system project offices.[41]

On October 29, General Boushey re-examined the Dyna-Soar requirements established by the April 13 memorandum of Dr. York. Orbital flight and testing of military subsystems could only be permitted, Dr. York insisted, if these efforts did not adversely affect the central objective of non-orbital, hypersonic flight. General Boushey reiterated the opinion of USAF headquarters: both sets of objectives should be definitely achieved. Assuming a total funding of $665 million, ARDC was directed to formulate a two-phase development approach for a 9,000 to 10,000 pound glider.[42]

By November 1, 1959, the Dyna-Soar office completed an abbreviated development plan in fulfillment of ARDC System Requirement 201. As suggested by the Office of the Secretary of Defense, the project office once again structured the program in a three-step approach. In Step I, a manned glider, ranging in weight from 6,570 to 9,410 pounds would be propelled to suborbital velocities by a modified Titan booster. Step II encompassed manned orbital flight of the basic glider and interim military operations. A weapon system, founded on technology from the previous steps, comprised Step III. The project office anticipated 19 air-drop tests to begin in April 1962; the first of eight unmanned, suborbital flights to occur in July 1963; and the first of eight piloted, suborbital launches to take place in May 1964. The first, manned, global flight of Step II was scheduled for August 1965. To accomplish this program, the project office estimated the development cost to total $623.6 million from fiscal year 1960 through 1966.[43] On November 2, the Weapons Board of Air Force headquarters approved the revised Dyna-Soar plan. The Air Council, in addition to sanctioning the three-step program, also approved of an ARDC and AMC arrangement concerning booster procurement.[44]

Generals Schriever and Anderson, on November 4, forwarded a joint ARDC and AMC letter to USAF headquarters. After detailing the essentials of the program, the two commanders outlined their agreement on booster procurement: the project office would utilize the "experience" of the ballistic division in obtaining a booster for Dyna-Soar. They further stated that the proposed program would make full use of existing national booster programs, essentially satisfying Dr. York's requirement, and would also attain Air Force objectives by achieving orbital velocities. General Schriever and General Anderson closed by urging the source selection process to be completed.[45]

Following this advice, the Secretary of the Air Force, on November 9, 1959, announced the Dyna-Soar contracting sources. The Boeing Airplane Company had won the competition and was awarded the systems contract. The Martin Company, however, was named associate contractor with the responsibility for booster development.[46] On November 17, Air Force headquarters directed the research and development command to implement Step I and to begin planning for Step II of the Dyna-Soar program.[47] Three days later, Dr. Charyk gave the Air Force authority to negotiate Step I contracts for fiscal year 1960. There was, however, an obstruction. The assistant secretary instructed the Deputy Chief of Staff for Development that, prior to obligating any funds for the Dyna-Soar program, now designated System 620A, Dr. Charyk's office would have to be given financial plans and adequate work statements. No commitments could be made before the Air Force had a concise understanding of the direction of the project.[48]

In an effort to obtain approval to obligate funds for fiscal years 1959 and 1960, General Boushey and some of his staff met with Dr. Charyk on November 24, and Dr. Charyk made it clear that he did not wish to release any funds for Dyna-Soar at that time. Instead, he was going to institute Phase Alpha, the purpose of which would be to examine the step-approach, the proposed booster, the vehicle size, and the flight test objectives. Dr. Charyk stated that no funds would be obligated until the Alpha exercise was completed.

Once Dyna-Soar was implemented, the assistant secretary wanted to review the program step-by-step and release funds as the program proceeded.[49] To cover the work carried on under Phase Alpha, the Air Force released a total of $1 million. Pending further approval by Dr. Charyk, obligations could not exceed this amount.[50]

NOTES

1. SDD 464L, Hqs. ARDC, 12 Dec. 1957.

2. Ltr., Col. H. M. Harlow, Dir., F-106 WSPO, ASC, AMC to Source Selection Bd., 25 Jan. 1958, subj.: Report of Working Group for System 464L; mangt. rpt., W. E. Lamar, Asst. Ch., Bomb. Ac. Div., Det. 1, Hqs. ARDC, 4 Feb. 1958, subj.: Hypersonic Strategic Weapon System.

3. Rpt., Source Selection Bd., ident. no. 58RDZ-9197, subj.: Summary of Contractor Proposals.

4. DSM WAR, 10 Apr. 1958; TWX, AFDRD-AN-31317, Hqs. USAF to Cmdr., Det. 1, Hqs. ARDC, 16 June 1958.

5. Ltr., Maj. Gen. R. P. Swofford, Jr., Acting DCS/Dev., Hqs. USAF to Cmdr., ARDC, 25 June 1958, subj.: Selection of Contractor for WS 464L (Dyna-Soar) Development.

6. Ltr., Maj. Gen. J. W. Sessums, Jr., Vice Cmdr., ARDC to Lt. Gen. R. C. Wilson, DCS/Dev., Hqs. USAF, 11 July 1958.

7. Ltr., Lt. Gen. D. L. Putt, DCS/Dev., Hqs. USAF to Dr. H. L. Dryden, Dir., NACA, 31 Jan. 1958; TWX, RDZPR-2-9-E, Hqs. ARDC to Cmdr., Det. 1, Hqs. ARDC, 13 Feb. 1958; memo., Gen. T. D. White, CS/AF and Dr. H. L. Dryden, Dir., NACA, 20 May 1958, subj.: Principles for Participation of NACA in the Development and Testing of the "Air Force System 464L Hypersonic Boost Glide Vehicle (Dyna-Soar I);" memo., Gen. White and T. K. Glennan, Administrator, NASA, 14 Nov. 1958, subj.: Principles for Participation of NASA in the Development and Testing of the "Air Force System 464L Hypersonic Boost Glide Vehicle (Dyna-Soar I)."

8. Ltr., Lt. Gen. R. C. Wilson, DCS/Dev., Hqs. USAF to Maj. Gen. J. W. Sessums, Jr., Vice Cmdr., ARDC, 23 July 1958.

9. Ltr., Lt. Gen. S. E. Anderson, Cmdr., ARDC to Lt. Gen. R. C. Wilson, DCS/Dev., Hqs. USAF, 24 July 1958.

10. Ltr., Lt. Gen. R. C. Wilson, Hqs. USAF to Lt. Gen. S. E. Anderson, Cmdr., ARDC, 12 Aug. 1958.

11. Ltr., Maj. Gen. V. R. Haugen, Asst. Dep. Cmdr/Weap. Sys., Det. 1, Hqs. ARDC to DCS/Dev., Hqs. USAF, 6 Aug. 1958.

12. Ltr., Col. J. L. Martin, Jr., Acting Dir., Adv. Tech., Hqs. USAF to Cmdr., Det. 1, Hqs. ARDC, 4 Sept. 1958, subj.: Action on Dyna-Soar.

13. TWX, RDZSXB-3117, Cmdr., Det. 1, Hqs. ARDC to Hqs. USAF, 16 Sept. 1958.

14. TWX, AFDAT-58885, Hqs. USAF to Cmdr., Det. 1, Hqs. ARDC, 30 Sept. 1958.

15. Chronology, Dyna-Soar WSPO, ident. no. 60WWZR-14775, hereafter cited as Dyna-Soar Chronology; DSM WAR, 31 Oct. 1958.

16. DSM WAR, 14 Nov. 1958; Dyna-Soar Chronology.

17. Preliminary Development Plan, System 464L, Det. 1, Hqs. ARDC, Nov. 1958, pp. 2, 8, 11, 32.

18. Dyna-Soar Chronology; TWX, AFDAT-54520, Hqs. USAF to Cmdr., Det. 1, Hqs. ARDC, 30 Dec. 1958.

19. TWX, RDZSXB-12-31619-E, Cmdr., Det. 1, Hqs. ARDC to Hqs. USAF, 31 Dec. 1958.

20. Memo., Dep. Secy. of Def. to SAF, 7 Jan. 1959.

21. TWX, AFDAT-55061, Hqs. USAF to Cmdr., Det. 1, Hqs. ARDC, 14 Jan. 1959; TWX, AFDAT-48049, Hqs. USAF to Cmdr., Det. 1, Hqs. ARDC, 16 Jan. 1959.

22. TWX, RDZSXB-30164-E, Cmdr., Det. 1, Hqs. ARDC to Hqs. USAF, 6 Feb. 1959.

23. TWX, Cmdr., Det. 1, Hqs. ARDC to Hqs. USAF, 13 Feb. 1959.

24. TWX, AFDAT-56643, Hqs. USAF to Cmdr., Det. 1, Hqs. ARDC, 17 Feb. 1959.

25. GOR 92, revised, Hqs. USAF, 17 Feb. 1959.

26. TWX, AFDAT-59299, Hqs. USAF to Cmdr., ARDC, 24 Apr. 1959.

27. SR 201, Hqs. ARDC, 7 May 1959.

28. Ltr., Maj. Gen. V. R. Haugen, Asst. Dep. Cmdr/Weap. Sys., Det. 1, Hqs. ARDC to Hqs. USAF, 15 May 1959, subj.: Dyna-Soar I Program Guidance.

29. Rpt., DSM, Det. 1, Hqs. ARDC, subj.: Dyna-Soar, Substantiation of RDZ Program.

30. TWX, AFDAT-51437, Hqs. USAF to Cmdr., Det. 1, Hqs. ARDC, 28 May 1959.

31. DSM WAR, 12 June 1959; Dyna-Soar Chronology.

32. Presn., W. E. Lamar, Dep. Dir/Dev., Dyna-Soar SPO, ASD to Hqs. AFSC, 20 Feb. 1963, subj.: History of Dyna-Soar (X-20) to Present; memo., Lt. Col. B. H. Ferer, Asst. Boost-Glide Sys. DCS/Dev., Hqs. USAF, 24 June 1959, subj.: Dyna-Soar Briefing to Dr. Charyk, Tuesday, 23 June 1959.

33. TWX, AFDAT-53166, Hqs. USAF to Cmdr., Det. 1, Hqs. ARDC, 10 July 1959.

34. TWX, RDG-23-7-5-E, Hqs. ARDC to Hqs. BMD, 23 July 1959; rpt., DSM, Det. 1, Hqs. ARDC, ident. no. 59RDZ-23128, subj.: Dyna-Soar Meeting, July-August 1959.

35. Memo., Dr. H. F. York, DDR&E, DOD to SAF and Dir., ARPA, DOD, 27 July 1959, subj.: Saturn, Dyna-Soar Propulsion.

36. Dyna-Soar Chronology.

37. Ltr., Brig. Gen. C. H. Terhune, Jr., Vice Cmdr., BMD to Det. 1, Hqs. ARDC, 13 Aug. 1959, subj.: Dyna-Soar Booster Evaluation.

38. Ltr., Brig. Gen. H. A. Boushey, Dir., Adv. Tech., DCS/Dev., Hqs. USAF to Hqs. ARDC, 29 Oct. 1959, subj.: Required Action on Dyna-Soar.

39. Ltr., Lt. Gen. W. F. McKee, Vice Cmdr., AMC to Cmdr., ARDC, 23 Sept. 1959, subj.: The Dyna-Soar Program.

40. TWX, Lt. Gen. B. A. Schriever, Cmdr., ARDC to Lt. Gen. S. E. Anderson, Cmdr., AMC, 12 Oct. 1959.

41. TWX, Lt. Gen. S. E. Anderson, Cmdr., AMC to Lt. Gen. B. A. Schriever, Cmdr., ARDC, 14 Oct. 1959.

42. Ltr., Brig. Gen. Boushey to Hqs. ARDC, 29 Oct. 1959, subj.: Required Action on Dyna-Soar.

43. Abbreviated Development Plan, System 464L, Dyna-Soar WSPO, Det. 1, Hqs. ARDC, 1 Nov. 1959.

44. DSM WAR, 6 Nov. 1959.

45. Ltr., Lt. Gen. B. A. Schriever, Cmdr., ARDC and Lt. Gen. S. E. Anderson, Cmdr., AMC to Hqs. USAF, 4 Nov. 1959, subj.: Dyna-Soar Selection.

46. DSM WAR, 13 Nov. 1959; TWX, RDZSXB-31253-E, Det. 1, Hqs. ARDC to Hqs. BMD, 10 Nov. 1959; TWX, RDZSXB-31261-E, DSM, Hqs. ARDC to Hqs. SAC, 13 Nov. 1959.

47. TWX, AFDAT-90938, Hqs. USAF to Cmdr., ARDC, 17 Nov. 1959.

48. Memo., Dr. J. V. Charyk, ASAF/Res. & Dev. to DCS/Dev., Hqs. USAF, 20 Nov. 1959, subj.: D&F 50-11-284 Dyna-Soar program.

49. Memo., Lt. Col. B. H. Ferer, Asst/Boost-Glide Sys., DCS/Dev., Hqs. USAF, 24 Nov. 1959, subj.: Assistant Secretary Air Force R&D Restrictions on Dyna-Soar Determinations and Findings.

50. TWX, AFDAT-95166, Hqs. USAF to Cmdr., ARDC, 7 Dec. 1959.

CHAPTER III

PHASE ALPHA AND ITS RESULTS

Before the Dyna-Soar Weapon System Project Office could undertake the suborbital Step I of the program, the Air Force had to institute Phase Alpha and appraise the Dyna-Soar approach to eventual manned orbital flight. Early in December 1959, the Aero and Space Vehicles Panel of the Scientific Advisory Board offered some recommendations concerning the objectives of this study. The panel pointed to the inadequacy of technical knowledge in the areas of aerodynamics and structures and, consequently, considered that development test programs to alleviate these deficiencies should be formulated during the study. Concerning the entire program, the scientific advisory group strongly supported the Dyna-Soar approach. While the program could be severely limited by a restricted budget and the absence of a high military priority, the Aero and Space Vehicles Panel insisted that Dyna-Soar was important because, if properly directed, it could yield significant information in the broad research areas of science and engineering.[1]

Dr. J. V. Charyk, Assistant Secretary of the Air Force for Research and Development, concurred with the position of the panel. In Alpha, emphasis would be placed on the identification and solutions of technical problems, and the objective of Step I would be the development of a test vehicle rather than a weapon system. Dr. Charyk then authorized the release of an additional $2.5 million for this study.[2]

On December 11, 1959, the Air Force and the Boeing Airplane Company had already signed a contract for the Alpha study, but the Air Force was undecided as to which contractors or Air Force agencies would provide Boeing with booster analyses. By the end of

January 1960, the Dyna-Soar office recommended that the Ballistic Missile Division and the Space Technology Laboratories provide the booster studies. Since Alpha had to be completed in March 1960, the project office did not consider that there was sufficient time to complete a contract with Martin for the Alpha study.[3] The Aeronautical Systems Center objected and maintained that the existing contracts with Boeing could not be extended to allow participation in booster studies.[4] Command headquarters disagreed and resolved the issue on February 3: the Ballistic Missiles Center would arrange contracts with the space laboratories and the Martin Company and the Aeronautical Systems Center would extend the Boeing contract.[5]

Booster information for Alpha was not the only problem; ARDC headquarters still had to settle the question of booster procurement for the entire Dyna-Soar program. Lieutenant General B. A. Schriever, Commander of ARDC, and Lieutenant General S. E. Anderson, Commander of AMC, had apparently delineated the authority of their respective commands in their November 4, 1959 letter, but a formal agreement had not been reached. Early in December 1959, General Schriever had completed an agreement within his command which assigned technical responsibility for booster development to the Ballistic Missiles Division. General Schriever hoped that General Anderson also intended to delegate commensurate contractual authority to the Ballistic Missiles Center.[6] General Anderson was essentially in agreement with General Schriever's position, but he objected to an agreement made between the ARDC project office and the ballistic division without participation of AMC elements. Consequently, the air materiel commander urged that the two commands complete a joint agreement concerning the development of the Dyna-Soar booster.[7]

On February 8, 1960, Generals Schriever and Anderson reached such an understanding which detailed the position of the west coast complex in the Dyna-Soar program. While management and financial authority for the entire program rested in the weapon system project office, the ballistic division and center, with the approval of the system office, would define the statements of work and complete contractual arrangements for the booster development. All changes in the booster program which significantly altered performance, configuration, cost, or schedules, however, would necessitate concurrence of the project office.[8]

In the middle of January 1960, Brigadier General H. A. Boushey, Assistant for Advanced Technology in Air Force headquarters, gave more specific instructions concerning the direction of the Phase Alpha study. The objective of this review was to examine selected configurations for controlled, manned reentry to determine the technical risks involved in each and to define a development test program for Step I.[9] In order to evaluate the efforts of Boeing, Martin, the ballistic division, and the space laboratories in this study, Colonel W. R. Grohs, Vice Commander of the Wright Aeronautical Development Division (WADD), then directed the formation of an ad hoc committee.[10] *

This group was established early in February with representation not only from the Wright division but also from the Air Force Flight Test Center, the Air Force Missile Test Center, the Air Materiel Command, and the National Aeronautics and Space Administration. The central objective of this committee was to determine the kind of research vehicle the Air Force required to solve the problems involving manned reentry from orbital flight. Consequently, the ad hoc committee contracted with several companies, which were placed under the direction of Boeing, to investigate the potentialities of several categories of configurations. Variable geometric shapes such as the drag brake of the AVCO Manufacturing Corporation, a folding-wing glider of Lockheed Aircraft, and an inflatable device of Goodyear Aircraft were all examined. The committee also analyzed ballistic shapes

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*With the formation of the Wright Air Development Division, on December 15, 1959, the management of weapon system development was transferred from ARDC headquarters to the Wright complex.

such as a modified Mercury Capsule of McDonnell and lifting body configurations offered by the ad hoc committee itself and General Electric. Finally, gliders with varying lift-to-drag ratios were also proposed by the committee, Bell Aircraft, Boeing, and Chance-Vought Aircraft.

After examining these various configurations, the ad hoc group concluded that the development and fabrication of a ballistic shape or a lifting body configuration with a lift-to-drag ratio up to 0.5 would only duplicate the findings of the National Aeronautics and Space Administration in its Mercury program. Conversely, a glider with a high lift-to-drag ratio of 3.0 would not only provide a maximum amount of information on reentry but would also demonstrate the greatest maneuverability in the atmosphere and allow the widest selection of landing sites. Such a glider, however, presented the most difficult design problems. Consequently, the ad hoc committee decided that a medium lift-to-drag glider, in the range of 1.5 to 2.5, offered the most feasible approach for advancing knowledge of reentry problems.[11]

At the end of March 1960, the Aero and Space Vehicles panel again reviewed the Dyna-Soar program with emphasis on the results of the Alpha study. If the overriding requirement were to orbit the greatest weight in the shortest development time, the panel reasoned that the modified ballistic approach was preferable. However, the members noted that gliders would advance technical knowledge of structures and would provide the greatest operational flexibility. The vehicles panel further emphasized the importance of attaining early orbital flight and, consequently, suggested a reexamination of the need for a sub-orbital Step I and more precise planning for the orbital Step II.[12]

The Dyna-Soar glider, as conceived by the Alpha group and the project office, was to be a low-wing, delta-shape vehicle weighing about 10,000 pounds. To undergo the heating conditions during reentry, the framework was to be composed of Rene' 41 braces which would withstand a temperature of 1800 degrees Fahrenheit. The upper surface of the glider was to be fabricated of Rene' 41 panels, where the temperature was expected to range from 500 to 1900 degrees. The lower surface was to be a heat shield, designed for a maximum temperature of 2700 degrees, and was to consist of molybdenum sheets attached to insulated Rene' 41 panels. The leading edge of the wings would have to withstand similar heat conditions and was to be composed of coated molybdenum segments. The severest temperature, ranging from 3600 to 4300 degrees, would be endured by the nose cap, which was to be constructed of graphite with zirconia rods.[13]

In conjunction with the ad hoc group, the Dyna-Soar project office completed, by April 1, 1960, a new development plan which further elaborated the three-step program presented in the November 1959 approach. Step I was directed towards the achievement of four objectives: exploration of the maximum heating regions of the flight regime, investigation of maneuverability during reentry, demonstration of conventional landing, and evaluation of the ability of man to function usefully in hypersonic flight. While Step I was limited to suborbital flight, the purpose of Step IIA was to gather data on orbital velocities and to test military subsystems, such as high resolution radar, photographic and infrared sensors, advanced bombing and navigation systems, advanced flight data systems, air-to-surface missiles, rendezvous equipment, and the requisite guidance and control systems. While Step IIB would provide an interim military system capable of reconnaissance and satellite inspection missions, the objective of Step III was a fully operational weapon system.

Whereas the last two steps were only outlined, the main consideration of the project office was the suborbital Step I. In order to demonstrate the flying characteristics of the glider up to speeds of Mach 2, the Dyna-Soar office scheduled a program of 20 air-drop tests from a B-52 carrier to begin in July 1963.* Beginning in November 1963, five unmanned flights were to be conducted in Mayaguana in the Bahama Islands and Fortaleza, Brazil, with velocities ranging from 9,000 to 19,000 feet per second. Eleven piloted flights, scheduled to start in November 1964, would then follow, progressively increasing the velocity to the maximum 19,000 feet per second and employing landing sites in Mayaguana, Santa Lucia in the Leeward Islands, and, finally, near Fortaleza.

To accomplish this Step I program, the Dyna-Soar office estimated that $74.9 million would be required for fiscal year 1961, $150.9 million for 1962, $124.7 million for 1963, $73.6 million for 1964, $46.8 million for 1965, and $9.9 million for 1966. Including $12.8 million for 1960, these figures totalled $493.6 million for the suborbital program.[14]

During the first week in April 1960, officials of the Dyna-Soar project office presented the new development plan and the results of Phase Alpha to Generals Schriever, Anderson, and Boushey, and the Strategic Air Panel and the Weapons Board of Air Force headquarters. On April 8, Dyna-Soar representatives explained the program to the Assistant Secretary of the Air Force for Research and Development, now Professor C. D. Perkins, and received his approval to begin work on the suborbital Step I.[15] On April 19, the Assistant Secretary of the Air Force for Materiel, P. B. Taylor, authorized negotiations of fiscal year 1961 contracts for this phase of the program.** The Department of Defense, on April 22, endorsed the new program and permitted the release of

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*For the air-drop program, the Dyna-Soar office was considering employment of either the XLR-11 or the AR-1 liquid rocket engines to propel the glider to specified speeds. Late in 1960, however, the project office decided to use a solid acceleration rocket not only for abort during launch but also for the air-drop tests.

**On April 24, 1961, Dr. Charyk, then Under Secretary of the Air Force, permitted contractual arrangements for the entire Step I program rather than for only particular fiscal years.

$16.2 million of fiscal year 1960 funds.[16] Consequently, on April 27, the Air Force completed a letter contract with the Boeing Airplane Company as system contractor. Source selection procedures had previously been initiated for the award of two associate contracts. On December 6, 1960, the Air Force granted authority to the Minneapolis-Honeywell Regulator Company for the primary guidance subsystem, and, on December 16, the Air Force gave responsibility to the Radio Corporation of America for the communication and data link subsystem.*

Air Force headquarters, on July 21, 1960, further recognized the three-step program by issuing System Development Requirement 19. With the segmented approach, the Air Force could develop a manned glider capable of demonstrating orbital flight, maneuverability during hypersonic glide, and controlled landings. Furthermore, Dyna-Soar could lead to a military system able to fulfill missions of space maneuver and rendezvous, satellite inspection, and reconnaissance. Headquarters looked forward to the first manned suborbital launch which was to occur in 1964.[17]

While the Step I program was approved and funded, the Dyna-Soar project office firmly thought that studies for the advanced phases of the program should also be initiated. In early August 1960, the project office recommended to ARDC headquarters that $2.32 million should be made available through fiscal year 1962 for this purpose. If these funds were released immediately, the project office anticipated completion of preliminary program plans for Steps IIA, IIB, and III by December 1961, January 1962, and June 1962, respectively.[18] Later in the month the Dyna-Soar office again

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*The Air Force granted three other associate contracts for the Dyna-Soar program. On June 8, 1960, the Martin Company received responsibility for the booster airframe, while, on June 27, the Air Force authorized the Aero-Jet General Corporation to develop the booster engines. Previously, on June 9, the Air Force made arrangements with the Aerospace Corporation to provide technical services for the Step I program.

reminded command headquarters of the urgency in releasing these funds.[19]

The apparent source of delay was that the authority to negotiate contracts, issued by Assistant Secretary Taylor on April 19, 1960, referred specifically to Step I of the program. Colonel E. A. Kiessling, Director of Aeronautical Systems in ARDC headquarters, met with Professor Perkins on September 22 and 23, and the assistant secretary agreed that this authority did not prohibit Step II and III studies. The restraint only applied to the expenditure of fiscal year 1961 funds for the purchase of equipment for the advanced phases.[20] * This decision was confirmed on October 12 when Air Force headquarters approved Steps II and III studies by issuing Development Directive 411.[22] ** ARDC headquarters then issued, on December 6, a system study directive for Step III and allotted $250,000 for this work.[24] By the middle of 1961, however, it was questionable whether the Air Force would continue the three-step approach. The Air Staff consequently postponed the Step III investigation, and early in 1962 command headquarters canceled the study.[25]

In the April 1960 development plan the Dyna-Soar office had proposed the employment of Titan I as the Step I booster. The

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*Colonel T. T. Omohundro, Deputy Director for Aeronautical Systems, ARDC headquarters, informed the Dyna-Soar office, on October 4, 1960, that Air Force headquarters would probably have to issue a new authority to negotiate contracts for Step II and III studies before funds could be released. Apparently, Colonel Kiessling had not told his deputy of Professor Perkins' previous decision.[21]

**On February 14, 1961, the Air Force and Boeing completed a contract for Step IIA and IIB studies with an effective date of November 9, 1960. Boeing was allotted $1.33 million and given until June 30, 1962 to complete the studies. With the assumption that a new orbital booster would provide Step II propulsion, Boeing concluded that it was feasible for the Dyna-Soar glider to perform military missions such as reconnaissance, satellite interception and inspection, space logistics, and bombardment. The last mission, however, the contractor considered could be performed with less expense by intercontinental ballistic missiles.[23]

first stage of this system was powered by the LR87-AJ-3 engine, capable of developing 300,000 pounds of thrust, while the second stage, an LR91-AJ-3 engine, could produce 80,000 pounds of thrust. This booster would be able to propel the Dyna-Soar glider to a velocity of 19,000 feet per second on a suborbital flight from Cape Canaveral to Fortaleza, Brazil. Professor Perkins, however, considered this booster marginal for Step I flights and, on November 28, 1960, requested the Air Force to examine the feasibility of employing Titan II for the suborbital step and a combination Titan II first stage and a Centaur-derivative upper stage for the orbital phase.[26] The Titan II was a two-stage liquid rocket and, unlike the Titan I, employed hypergolic, storable propellants. The first stage consisted of an XLR87-AJ-5 engine, capable of producing 430,000 pounds of thrust, while the second stage was an XLR91-AJ-5 unit, capable of delivering 100,000 pounds of thrust.

Late in December 1960 Mr. R. C. Johnston of the Dyna-Soar office and Major G. S. Halvorsen of the Ballistic Missiles Division presented the advantages of Titan II to ARDC headquarters, and the proposal to employ the advanced Titan received the endorsement of General Schriever. A presentation to Air Force headquarters followed. Assistant Secretary Perkins appeared satisfied with the recommendation but stated that Department of Defense approval would probably not be given unless the booster change was considered in conjunction with an anticipated funding level of $70 million for fiscal year 1962, instead of the requested $150 million.[27]

A few days later the project office protested the $70 million level and insisted that it would result in serious delays to the program. Regardless of the funding arrangements, the Dyna-Soar office urged approval of Titan II.[28] Colonel Kiessling concurred with this position and appealed to USAF headquarters. Even with the proposed low funding level, the Director of Aeronautical Systems stated employment of the Titan II promised a substantially improved Dyna-Soar program and this booster change should be immediately approved.[29]

Mr. Johnston and Major Halvorsen again went to Air Force headquarters. After receiving the approval of Major General M. C. Demler, Director of Aerospace Systems, the Dyna-Soar representatives informed the Strategic Air Panel of the attributes of Titan II. Discussion of the panel centered on the availability of the new booster for Step I flights, limitations of the combination Titan II and Centaur-derivative for the orbital booster, and the apparent inadequate funding level for fiscal year 1962. In spite of some doubts, the panel approved the proposed booster for Dyna-Soar I and further recommended that approximately $150 million should be allocated for fiscal year 1962.[30]

At the request of Assistant Secretary Perkins, General Demler had prepared a summary on the advantages of Titan II over the earlier version. The Director of Aerospace Systems insisted that Titan I was barely sufficient for achieving the objectives of Step I and, furthermore, could not be modified to provide orbital velocities for the glider. The April 1960 development plan had stipulated that with Titan I the first unmanned ground-launch would occur in November 1963, while employment of the more powerful Titan II would only push this date back to January 1964. General Demler pointed out that if the program were limited to $70 million, October 1964 would be the date for the first unmanned ground-launch with Titan I while December 1964 would be the date for Titan II. The aerospace director estimated that with a $150 million level for fiscal year 1962 the development of Titan II would cost an additional $33 million, while the cost would still be $26 million with the $70 million funding level. General Demler considered that the total booster cost for Step I and II employing the Titan I and then a Titan II-Centaur combination would be $320.3 million. If Titan II were immediately used for Step I, the booster cost would be $324.3 million. Thus the additional cost for using the more powerful booster in the first phase of the Dyna-Soar program only amounted to $4.2 million. The conclusion was obvious; however, General Demler refrained from making recommendations.[31]

Following the briefing to the Strategic Air Panel, Mr. Johnston and Major Halvorsen gave the Titan II presentations to the Weapons Board. The members were familiar with the logic of General Demler's summary, and, while expressing interest in the early attainment of orbital flight, they endorsed the change to Titan II. The board recommended that Air Force headquarters immediately instruct ARDC to adopt the new booster.[32] However, Major General V. R. Haugen and Colonel B. H. Ferer, both in the office of the Deputy Chief of Staff for Development, decided to seek the approval of the Department of Defense. The Titan II presentations were then given to Mr. J. H. Rubel, Deputy Director of Defense for Research and Engineering. While reiterating the necessity of a $70 million budget, Mr. Rubel agreed to the technical merits of Titan II. On January 12, 1961, Air Force headquarters announced approval of this booster for Step I flights.[33]

During these discussions over Titan II, it was apparent that the Department of Defense was seriously considering limiting the fiscal year 1962 figure to $70 million. This financial restriction was confirmed on February 3 when Air Force headquarters directed the Dyna-Soar office to reorient the Step I program to conform with this lower funding level.[34] By the end of the month the project office and the Dyna-Soar contractors had evaluated the impact of this reduction on the program. It was clear that flight schedules would be set back almost one year.[35]

Apparently Department of Defense officials relented, for, on March 28, 1961, Air Force headquarters announced that the fiscal year 1962 level would be set at $100 million. The following day Colonel W. L. Moore, Dyna-Soar Director, and his Deputy Director for Development, W. E. Lamar, reported on the status of the program to Air Force headquarters. Both Dr. Charyk and Major General Haugen directed that the program be established on a "reasonable" funding level. Colonel Moore noted that a definition of this statement was not offered.[36] Finally, on April 4, headquarters of the Air Force Systems Command (AFSC) officially instructed the program office to redirect Dyna-Soar to a $100 million level for fiscal year 1962.[37] *

By April 26, 1961, the Dyna-Soar office had completed a system package program. This plan further elaborated the familiar three-step approach. Step I would involve suborbital missions of the Dyna-Soar glider boosted by the Titan II. For the research and development of this program, the Dyna-Soar office stated that $100 million was required for fiscal year 1962, $143.3 million for 1963, $114.6 million for 1964, $70.7 million for 1965, $51.1 million for 1966, and $9.2 million for 1967. If these funds were allotted, the first air-drop would take place in January 1964, the first unmanned ground-launch in August 1964, and the first manned ground-launch in April 1965.

The objective of Step IIA was to demonstrate orbital flight of the Dyna-Soar vehicle on around-the-world missions from Cape Canaveral to Edwards Air Force Base. The program office proposed the testing on these flights of various military subsystems such as weapon delivery and reconnaissance subsystems. Because of high cost, the Dyna-Soar office did not recommend the evaluation of a space maneuvering engine, space-to-earth missiles, or space-to-space weapons during Step IIA flights. For fiscal years 1963 through 1968, the program office estimated that this phase of Step II would total $467.8 million and, assuming the selection of the orbital booster by the beginning of fiscal year 1962, reasoned that the first manned orbital flight could be conducted in April 1966.

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*On April 1, 1961, the Air Research and Development Command, by acquiring the procurement and production functions from the Air Materiel Command, was reorganized as the Air Force Systems Command. At Wright-Patterson Air Force Base, the Wright Air Development Division combined with the Aeronautical Systems Center to become the Aeronautical Systems Division (ASD).

In Step IIB, the Dyna-Soar vehicle would provide an interim operational system capable of fulfilling reconnaissance, satellite interception, space logistics, and bombardment missions. With the exception of $300,000 necessary for an additional Step IIB study, the Dyna-Soar office did not detail the financial requirements for this phase, however, it did anticipate a Step IIB vehicle operating by October 1967. The program office looked further in the future and maintained that $250,000 would be necessary for each fiscal year through 1964 for studies on a Step III weapon system, which could be available by late 1971.[38]

In the April 1961 system package program, the Dyna-Soar office outlined an extensive Category I program, consisting of structural and environmental, design, and aerothermodynamic testing, which was necessary for the development of the glider. In order to verify information obtained from this laboratory testing, the system office recommended participation in another test program which would place Dyna-Soar models in a free-flight trajectory.[39] The first approach which the Dyna-Soar office considered was System 609A of the Ballistic Missiles Division.

During the March 1960 review, the Aero and Space Vehicles Panel emphasized the difficulty in predicting behavior of structures utilizing coated heat shields and recommended Dyna-Soar participation in the 609A program.[40] The system office agreed and decided to place full-scale sections of the glider nose on four hyper-environmental flights.[41] * Although subsequent planning

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*Models of the AVCO drag brake were also scheduled to ride 609A launches. In February 1960, Air Force headquarters had transferred the management of this project from the Directorate of Advanced Systems Technology, WADD, to the Dyna-Soar Weapon System Project Office. In March, the Air Force granted AVCO a study contract, and, in July, ARDC headquarters approved a development program for the drag brake. Air Force headquarters was reluctant to authorize funds, and the program was terminated in December. Nevertheless, in February 1961, Major General J. R. Holzapple, WADD Commander, reinstated research on certain technical areas of the drag brake program.[42]

reduced the number to two flights, command headquarters refused to release funds for such tests, and, consequently, Colonel Moore terminated Dyna-Soar flights in the System 609A test program on October 5. The project director gave several reasons for this decision: low probability of obtaining sufficient data with only two flights, insufficient velocity of the boosters, and high cost for Dyna-Soar participation.[43]

Air Force headquarters was concerned over this cancellation and emphasized to ARDC headquarters that the absence of a free-flight test program for Dyna-Soar failed to carry out assurances previously given to the Department of Defense.[44] The National Aeronautics and Space Administration had another approach which it had been proposing since May 1960. Dyna-Soar models constructed by both NASA and the Air Force would be placed on RVX-2A reentry vehicles and boosted by Atlas or Titan systems. Project office engineers could thereby obtain data on heat transfer and aerodynamic characteristics. By November 1960, the Dyna-Soar office was seriously considering verification of laboratory data by this RVX-2A program.[45]

In May 1961, Major General W. A. Davis, ASD commander, emphasized to AFSC headquarters the requirements for RVX-2A tests: funds and space on Titan II launches.[46] After two more appeals by the program office, Major General M. F. Cooper, Deputy Chief of Staff for Research and Engineering, gave the position of AFSC headquarters. Placing a reentry vehicle with Dyna-Soar models on the Titan II would impose several limitations on the test schedule of the booster requiring several modifications to the airframe and the launch facilities. General Cooper further stated that the $10 million estimated by NASA officials for the RVX-2A program would necessitate approval by Air Force headquarters.[47] Consequently, General Cooper intended to incorporate this program in a future Dyna-Soar development plan. The RVX-2A proposal was included in a October 7, 1961 plan for the development of a Dyna-Soar weapon system; however, this program did not receive the approval of USAF headquarters.[48] The attempt by the Dyna-Soar office to provide a specific program for free-flight verification of its laboratory test data ended at that point.

The April 1961 system package program also reflected changes in the Dyna-Soar flight plan. While 20 air-drop tests were still scheduled, only two unmanned ground-launches, instead of the previously planned four, were to be conducted.[49] On the first flight, the Titan II would accelerate the glider to a velocity of 16,000 feet per second, reaching Santa Lucia. During the second unmanned launch, the vehicle would attain a velocity of 21,000 feet per second and land near Fortaleza. Twelve manned flights were then planned with velocities ranging from 16,000 to 22,000 feet per second. If the two additional vehicles for unmanned launches were not expended, additional piloted flights would then take place.[50]

The scheduling of flights to Fortaleza, however, was becoming academic. As early as June 1960, Air Force headquarters notified ARDC headquarters that the State Department was concerned over the problem of renewing an agreement with Brazil for American military use of its territory.[51] This subject reappeared in May 1961 when the acting Director of Defense for Research and Engineering, J. H. Rubel, informed the Department of the Air Force that discussions with State Department officials indicated the difficulty, if not the impossibility, of obtaining a landing site for Dyna-Soar in Brazil.[52] Unless Air Force headquarters would tolerate increased costs, reduced flight test objectives, or employment of a new booster, the Dyna-Soar office thought that a landing field in Brazil was essential. The program office stated that employment of alternative landing sites would seriously affect the conduct of Category II flights and would probably prevent attainment of important research objectives.[53] Although Dr. Brockway McMillan, Assistant Secretary of the Air Force for Research and Development, reiterated this position to the Department of Defense, the subject of a Fortaleza landing site did not assume a greater significance because the Air Force was already seriously questioning the need for suborbital flight.54

From January 1960 through April 1961, the Dyna-Soar program office had defined the three-step program and had implemented the suborbital phase. While Air Force headquarters had approved the April 1960 development plan, it had not sanctioned the more detailed April 1961 system package program. The reason for this suspended action was apparent. The Dyna-Soar office was engaged in a study which promised to eliminate suborbital flight, accelerate the date for the first manned orbital launch, and, consequently, radically alter the three-step approach.

NOTES

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2. Memo., J. V. Charyk, ASAF/Res. & Dev., to DCS/Dev., Hqs. USAF, 4 Jan. 1960, subj.: Dyna-Soar "Phase Alpha" Program.

3. DSM WAR, 18 Dec. 1959, 15 Jan. 1960; TWX, RDZSXB-30061-E, Hqs. WADD to Hqs. ARDC, 20 Jan. 1960.

4. TWX, RDZSXB-1-1420-E, Hqs. WADD to Hqs. ARDC, 28 Jan. 1960.

5. DSM WAR, 5 Feb. 1960.

6. Ltr., Lt. Gen. B. A. Schriever, Cmdr., ARDC to Lt. Gen. S. E. Anderson, Cmdr., AMC, 5 Dec. 1959, subj.: Management of Dyna-Soar Project; memo., Hqs. ARDC and Hqs. BMD, subj.: Statement of Agreement, System 620A, Dyna-Soar I, for the Air Force Ballistic Missiles Division, ARDC.

7. Ltr., Lt. Gen. S. E. Anderson, Cmdr., AMC to Lt. Gen. B. A. Schriever, Cmdr., ARDC, 11 Dec. 1959, subj.: Management of the Dyna-Soar Program.

8. Memo., Lt. Gen. S. E. Anderson, Cmdr., AMC and Lt. Gen. B. A. Schriever, Cmdr., ARDC, subj.: AMC and ARDC Management Procedures for the Dyna-Soar Program, 8 Feb. 1960.

9. Ltr., Brig. Gen. H. A. Boushey, Asst/Adv. Tech., DCS/Dev., Hqs. USAF to Hqs. ARDC, 15 Jan. 1960.

10. Ltr., Col. W. R. Grohs, Vice Cmdr., WADD to Dep/Adv. Sys., DSM, WADD, 27 Jan. 1960, subj.: Formation of Ad Hoc Group for Dyna-Soar.

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12. Rpt., Aero & Space Vehicles Panel, SAB, 15 Apr. 1960, subj.: Dyna-Soar and Phase Alpha Review.

13. System Development Plan, Dyna-Soar (Step I) Program, 620A, Dyna-Soar WSPO, WADD, 1 Apr. 1960, pp. III-8 to III-12, III-49 to III-52, III-65 to III-72, III-195 to III-207; System Package Program, System 620A, Dyna-Soar SPO, ASD, 26 Apr. 1961, pp. 84-92, 132-139, 182-187.

14. System Development Plan, Dyna-Soar (Step I) Program, 620A, Dyna-Soar WSPO, WADD, 1 Apr. 1960, pp. III-1 to III-2, III-267 to III-272, IV-1 to IV-2, V-i, VIII-1, IX-1.

15. DSM WAR, 8, 16 Apr. 1960.

16. TWX, AFDAT-89082, Hqs. USAF to Hqs. ARDC, 26 Apr. 1960.

17. SDR 19, Hqs. USAF, 21 July 1960.

18. Ltr., Dyna-Soar WSPO, WADD, to Hqs. ARDC, subj.: Dyna-Soar Step II and Step III Funding, 2 Aug. 1960.

19. TWX, WWZRM-8-1041-E, Hqs. WADD to Hqs. ARDC, 23 Aug. 1960.

20. Memo., Col. E. A. Kiessling, Dir., Aero. Sys., Hqs. ARDC, 27 Sept. 1960, subj.: Dyna-Soar Step II and Step III Funding.

21. Ltr., Col. Kiessling, Hqs. ARDC to Hqs. WADD, subj.: WADD Dyna-Soar Step II and Step III Funding, 4 Oct. 1960.

22. DD 411, Hqs. USAF, 12 Oct. 1960.

23. Rpt., Dyna-Soar SPO, ASD, Dec. 1962, subj.: Evaluation of the Dyna-Soar Step IIA and Step IIB Studies, pp. 1, 11.

24. SSD, Hqs. ARDC, 6 Dec. 1960, subj.: Dyna-Soar Step III Study.

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26. TWX, AFDSD-66668, Hqs. USAF to Hqs. ARDC, 5 Dec. 1960.

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29. TWX, RDRAS-6-1-8, Hqs. ARDC to Hqs. USAF, 6 Jan. 1961.

30. Memo., R. C. Johnston, Ch., Booster Br., Dyna-Soar WSPO, WADD, 12 Jan. 1961, subj.: Trip Report to Hqs. USAF, 9-11 Jan. 1961, Titan II Booster Presentation.

31. Rpt., Maj. Gen. M. C. Demler, Dir., Aerospace Sys. Dev., DCS/Dev., Hqs. USAF, subj.: System 620A, Dyna-Soar (Step I) Booster.

32. Memo., R. C. Johnston, Ch., Booster Br., Dyna-Soar WSPO, WADD, 12 Jan. 1961, subj.: Trip Report to Hqs. USAF, 9-11 Jan. 1961, Titan II Booster Presentation.

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37. TWX, SCRAS-3-4-2, Hqs. AFSC to Hqs. ASD, 4 Apr. 1961.

38. System Package Program, System 620A, Dyna-Soar SPO, ASD, 26 Apr. 1961, pp. 42, 411, 446-447, 454, 460-474, 487a, 489-490, 502, 510, 519, 522.

39. Ibid., p. 189.

40. Rpt., Aero & Space Vehicles Panel, SAB, 15 Apr. 1960, subj.: Dyna-Soar and Phase Alpha Review.

41. Memo., W. E. Lamar, Ch., Dir. Sys. Engg., Dyna-Soar WSPO, WADD, subj.: Conference at NASA Regarding RVX-2 Test for Dyna-Soar; System Development Plan, Dyna-Soar (Step 1) Program, 620A, Dyna-Soar WSPO, WADD, 1 Apr. 1960, p. III-77; TWX, WWZRB-23-8-1017, Hq. WADD to Hqs. BMD, 23 Aug. 1960.

42. Ltr., Col. W. L. Moore, Jr., Ch., Dyna-Soar WSPO, WADD to J. A. Boykin, DSM, WADD, 1 Feb. 1960, subj.: AVCO Drag Brake Project; TWX, WWZRB-6-4-E, Hqs. WADD to Hqs. BMD, 14 June 1960; memo., J. B. Trenholm, Jr., Asst. Dir., Dyna-Soar SPO, WADD, 21 Feb. 1961, subj.: AVCO Drag Brake-Project 6065; ltr., C. B. Hargis, Jr., Asst. Ch., Dyna-Soar WSPO, WADD to Hqs. BMD, 1 Apr. 1960, subj.: AVCO Drag Brake Program, Booster Data, and Availability Requirements; DSM WAR, 1 Apr. 1960, 1 July 1960, 2 Aug. 1960, 2 and 16 Sept. 1960, 6 Jan. 1961; TWX, RDRAS-14-12-26, Hqs. ARDC to Hqs. WADD, 14 Dec. 1962.

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46. Ltr., Maj. Gen. W. A. Davis, Cmdr., ASD to Hqs. AFSC, subj.: Aeronautical Systems Division Free Flight Environmental Test Program, 2 May 1961.

47. Ltr., Maj. Gen. M. F. Cooper, DCS/Res. & Engg., Hqs. AFSC to Dr. I. H. Abbott, Dir., Adv. Res. Prog., NASA, 28 June 1961, subj.: Dyna-Soar Reentry Research Program.

48. Abbreviated Development Plan, System 620A, Dyna-Soar SPO, ASD, 7 Oct. 1961, subj.: Manned Military Space Capability, p. 64.

49. Memo., W. M. Ritchey, Asst. Test Force Dir., Dyna-Soar WSPO, WADD, 1 Nov. 1960, subj.: Meeting to Consider System Development Test Approach; DSM WAR, 4 Nov. 1960.

50. System Package Program, System 620A, Dyna-Soar SPO, ASD, 26 Apr. 1961, pp. 306-307.

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52. Memo., J. H. Rubel, Acting DDR&E, DOD to SAFUS, 3 May 1961, subj.: Dyna-Soar Landing Site in Brazil, in files Dyna-Soar Sys. Staff Ofc., DCS/Sys. & Log., Hqs. USAF.

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CHAPTER IV

REDIRECTION

When Brigadier General M. B. Adams, Deputy Director of Systems Development in Air Force headquarters, forwarded Development Directive 411 in October 1960, he initiated a series of studies which eventually resulted in a redirection of the Dyna-Soar program. General Adams instructed the Air Research and Development Command to formulate a "stand-by" plan for achieving orbital flight with the Step I glider at the earliest possible date.[1] In December, the Dyna-Soar office was ready with such a proposal. By merging Steps I and IIA into a continuous development and employing an orbital booster for both suborbital and orbital flights, the time for the first manned orbital launch could be accelerated by as much as 17 months over the three-step schedules.[2]

Depending on either a March 1961 or a November 1961 approval date, Dyna-Soar officials estimated that by using a Titan II in combination with a Centaur derivative, the program would cost either $726 million or $748 million. If Saturn C-1 was designated, the figures would be $892 million or $899 million. The total, however, for a separate suborbital Step I and an orbital Step IIA would approximate $982.6 million. This financial difference between "stand-by" and the three-step approach stemmed from the employment of the same booster for both suborbital and orbital flights. The Dyna-Soar office favored this accelerated approach and recommended that ARDC headquarters immediately approve "stand-by."[3] Command headquarters did not agree and took the position that "stand-by" would only be approved when the international situation necessitated a higher priority and additional funds for Dyna-Soar.[4]

The logic of employing the same booster for Steps I and IIA pointed to a further conclusion. On May 4, 1961, Boeing officials proposed another plan for acceleration. This "streamline" approach encompassed the elimination of suborbital flight, temporary employment of available subsystems, and the use of Saturn C-1. Assuming a June 1961 approval date, Boeing representatives anticipated the first unmanned orbital flight to occur in April 1963, instead of August 1964 as scheduled in the three-step approach.[5]

Temporary subsystems would only decrease system reliability, the program office reasoned, and, consequently, Boeing's proposal was not entirely acceptable. Dyna-Soar officials considered that the key to accelerating the orbital flight date was not only the question of booster availability, but also the time required to develop the various glider subsystems. If funding for fiscal year 1962 were increased, it would be possible to accelerate the glider schedules and advance the orbital flight date.

By the end of June, the program office had refined Boeing's original plan. The first phase, "streamline," involved the development of an orbital research vehicle. The purpose of the second phase was the development and testing of military subsystems with the final phase resulting in an operational weapon system. Either a modified Saturn booster, a Titan II with a hydrogen-oxygen second stage, or a Titan II augmented by solid propellant engines, was acceptable for the "streamline" phase. The program office now estimated that this phase would cost a total of $967.6 million, with the first unmanned orbital flight occurring in November 1963.[6]

While the Dyna-Soar office was considering ways to accelerate the orbital flight date of its glider, the newly established Space Systems Division (SSD) completed, on May 29, 1961, two development plans for demonstrating orbital and far-earth orbital flight of a lifting body design. Essentially, the objective of the Advanced Reentry Technology program (ART) was to determine whether ablative or radiative heat protection was more feasible for lifting reentry.[7] The second program advanced by SSD was a manned satellite inspector proposal, SAINT II.

The space division had under its cognizance a SAINT I program, the purpose of which was the development of an unmanned prototype, inspector vehicle. The SAINT II proposal involved the development of a manned vehicle, capable of achieving precise orbital rendezvous and fulfilling space logistic missions. This lifting body would be able to maneuver during reentry and accomplish conventional landing at a preselected site. Officials of the space division listed several reasons why the Dyna-Soar configuration could not, in their opinion, accomplish SAINT II missions. The reentry velocity of Dyna-Soar could not be significantly increased because of the inadaptability of this configuration to ablative heat protection. Furthermore, winged-configurations did not permit sufficient payload weights and incurred structural penalties to the booster. Finally, rendezvous and logistic missions would require prohibitive modifications to the Dyna-Soar glider.

The proposed SAINT II demonstration vehicle was to be a two-man lifting, reentry craft launched by a Titan II and Chariot combination. This Chariot upper stage would employ fluorine and hydrazine propellants and would produce 35,000 pounds of thrust. The vehicle would be limited to 12,000 pounds, but, with approval of an Air Force space launch system, the weight could be increased to 20,000 pounds. Twelve orbital demonstration launches were scheduled, with the first unmanned flight occurring early in 1964 and the initial manned launches taking place later that year. From fiscal year 1962 through 1965 this program would require $413.9 million.[8]

After examining the space division proposal and the Dyna-Soar plan for acceleration, General B. A. Schriever, AFSC commander, deferred a decision on Dyna-Soar until the relationship between "streamline" and SAINT II was clarified. Moreover, further analysis of an orbital booster for Dyna-Soar would have to be accomplished.[9]

From May 1 through 12, 1961, a Dyna-Soar technical evaluation board, composed of representatives from the Air Force Systems Command, the Air Force Logistics Command (AFLC), and the National Aeronautics and Space Administration, had considered 13 proposals for orbital boosters from the Convair Division, the Martin Company and NASA. The evaluation board decided that the Martin C plan was the most feasible approach. The first stage of this liquid booster consisted of an LR87-AJ-5 engine, capable of producing 430,000 pounds of thrust, while the second stage, with a J-2 engine, could deliver 200,000 pounds of thrust.[10]

The Dyna-Soar Directorate of the Space Systems Division, having the responsibility for developing boosters for System 620A, also made a recommendation on the Step IIA propulsion. On July 11, Colonel Joseph Pellegrini informed the Dyna-Soar office that his directorate favored employment of the projected Space Launch System A388. This proposal was an outgrowth of an SSD study on a Phoenix series of varying combinations of solid and liquid boosters to be used in several Air Force space missions. Phoenix A388 was to have a solid first stage, which could produce 750,000 pounds of thrust, and a liquid propellant second stage, using the J-2 engine.[11]

On August 3 and 4, 1961, Colonel Walter L. Moore, Jr., director of the Dyna-Soar program, brought the "streamline" proposal before the Strategic Air Panel, the Systems Review Board, and the Vice Chief of Staff. The program director pointed out that by eliminating suborbital flight the first air-drop would occur in mid-1963; the first unmanned orbital flight in 1964; and the first piloted orbital launch in early 1965. In comparison, the first piloted Step IIA flight had been scheduled for January 1967. Not only would the orbital flight date be accelerated, but considerable financial savings would also accrue. Colonel Moore now estimated that the combined cost of Steps I and IIA was projected at $1.201 billion, while the figure for "streamline" would run $1.026 billion. The director concluded by emphasizing that Dyna-Soar provided the most effective solution to an Air Force manned space program, and "streamline" was the most expeditious approach to piloted orbital flight.[12]

Officials from SSD and the Aerospace Corporation presented their considerations for a "streamline" booster. At this point it was clear that previous SSD evaluations for a Step IIA booster were simply incorporated in the "streamline" analysis. The first choice of Aerospace and SSD officials was again their proposed Phoenix space launch system. Assuming a November 1961 approval date, Phoenix A388 allowed the first unmanned launch to occur in July 1964, and, based on an 18-flight Dyna-Soar program, the cost for Phoenix development from fiscal year 1962 through 1966 would total $183.3 million. The second option was the Soltan, derived by attaching two 100-inch diameter solid propellant engines to the Titan II. The projected Soltan schedule permitted the same launch date as the Phoenix, but the cost was estimated at $325.4 million. Although the Saturn C-1 allowed an unmanned launch date in November 1963 and the cost would total $267.2 million, this booster was the third choice, largely because it was deemed less reliable. The space division representatives then concluded their part of the presentation by discussing the merits of ART and SAINT II.[13]

The Assistant Secretary of the Air Force for Research and Development, Dr. Brockway McMillan, was not as enthusiastic for acceptance of the Phoenix system. While he did not recommend use of the Saturn, Dr. McMillan though that the Air Force should seriously consider the fact that the big NASA booster would provide the earliest launch date for Dyna-Soar. The assistant secretary believed, however, that an Atlas-Centaur combination would be the most feasible space launch vehicle for 10,000 pound payloads through 1965. After this time period, Dr. McMillan favored Soltan.[14]

Prior to these briefings, General Schriever was already convinced that Dyna-Soar had to be accelerated. He further believed that the best selection for the booster was Phoenix A388.[15] On August 11, he informed ASD, SSD, and his Deputy Commander for Aerospace Systems, Lieutenant General H. M. Estes, Jr., that "streamline" had the approval of AFSC headquarters and had to be "vigorously supported" by all elements of the command. Yet, the acceleration of Dyna-Soar was not that simple. The AFSC commander was still concerned over the duplication of the manned SAINT proposal and an orbital Dyna-Soar. He stated that these plans constituted a complex, and, at that point, an indefinable approach to military space flight which could not be presented to USAF headquarters. Consequently, General Schriever directed that a Manned Military Space Capability Vehicle study be completed by September. This proposed program would consist of "streamline," and a Phase Beta study which would determine vehicle configuration, boosters, military subsystems, and missions for an operational system which would follow Dyna-Soar. General Schriever also directed that the applied research programs of his command be reviewed to assure contributions to Dyna-Soar and far-earth orbital flights.[16]

During an August 1961 meeting of the Designated Systems Management Group, the Secretary of the Air Force, Eugene M. Zuckert, commented on the question of Dyna-Soar acceleration.* He directed the three-step approach to continue until the position of Dyna-Soar in a manned military space program was determined. Within the confines of the $100 million fiscal year 1962 budget, the secretary stated that action could be taken to facilitate the transition from a Step I to a "streamline" program. Finally, he requested a study on various approaches to manned military orbital flight.[18]

Under the direction of General Estes, a committee was formed in mid-August 1961 with representation from the Air Force Systems Command, RAND, MITRE, and the Scientific Advisory Board for the purpose of formulating a manned military space plan. The work of the committee was completed by the end of September with diverse sets of recommendations.

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*In early April 1961, Lieutenant General R. C. Wilson, Deputy Chief of Staff for Development, appeared concerned with the management of Air Force headquarters over the Dyna-Soar program. Although the Air Staff had devoted considerable attention to this program, it had not always been successful in affecting the decisions of the Secretary of the Air Force or the Secretary of Defense. General Wilson indicated to General C. E. LeMay, the Vice Chief of Staff, that this situation could be alleviated if the program were placed under the management of the Air Force Ballistic Missile and Space Committee. General LeMay, on May 5, concurred and pointed out that the Department of the Air Force would have to place increasing emphasis on Dyna-Soar because it was a system leading to manned space flight. Dr. J. V. Charyk, the Air Force under secretary, disagreed and thought that since Dyna-Soar was primarily a research project, transfer of the management in the department should be deferred until a Dyna-Soar weapon system was under development. On July 25, the Secretary of the Air Force replaced the ballistic and space committee with the Designated Systems Management Group. Composed of important officials in the Department of the Air Force, this group was to assist the Secretary of the Air Force in managing significant programs. By August 1, 1961, the Dyna-Soar program was listed as one of the systems under the jurisdiction of the designated management group.[17]

One of the working groups, chaired by a representative from the Aerospace Corporation, favored terminating the Dyna-Soar program and redirecting Boeing's efforts to the development of a lifting body. Such an approach would cost $2 billion. A second alternative was to accelerate a suborbital Dyna-Soar program, cancel the orbital phase, and initiate studies for far-earth, orbital flights. This proposal would total $2.6 billion. The least feasible approach, this group considered, was to implement "streamline," and initiate a Phase Beta. Such a program would be the most expensive, totalling $2.8 billion.[19]

The opposite position was assumed by a panel of Scientific Advisory Board members, chaired by Professor C. D. Perkins, which strongly supported the last alternative of the Aerospace group. The Perkins group thought that military applications of a lifting body approach did not offer more promise than Dyna-Soar. To emphasize this point, the group questioned the control characteristics of a lifting body design which could make the execution of conventional landings hazardous. The group further argued that "streamline" should be directed towards defining military space objectives and insisted that a Phase Beta and an applied research program should be undertaken before considering an advanced Dyna-Soar vehicle.[20]

General Estes reached his own conclusions about a manned military space study. "Streamline" should receive Air Force approval; however, it should have unquestionable military applications, namely satellite inspection and interception missions. The deputy commander doubted that a Dyna-Soar vehicle could accomplish far-earth orbital flights and undergo the resulting reentry velocity, ranging from 35,000 to 37,000 feet per second, and, consequently, he firmly stated that a Phase Beta study, conducted by Boeing, was necessary to determine a super-orbital design for Dyna-Soar.[21]

Secretary of Defense Robert S. McNamara also made a pronouncement on Dyna-Soar. After hearing presentations on the program and the military space proposal of SSD, the secretary seriously questioned whether Dyna-Soar represented the best expenditure of national resources.[22] From this encounter with the defense department, the Air Staff derived a concept which was to dominate the Dyna-Soar program. Before military applications could be considered, the Air Force would have to demonstrate manned orbital flight and safe recovery.[23]

During a meeting of the Designated Systems Management Group in early October 1961, it was very clear that the Air Force had decided in favor of "streamline." The management group had severely criticized SAINT II by insisting that the projected number of flight tests and the proposed funding levels were too unrealistic. As a result of this review, the Department of the Air Force prohibited further use of the SAINT designation.[24]

Dyna-Soar officials completed, on October 7, 1961, an abbreviated development plan for a manned military space capability program. The plan consisted of "streamline;" a Phase Beta study, which would determine approaches to the design of a super-orbital Dyna-Soar vehicle; supporting technological test programs; and an applied research program. The objectives of the proposed Dyna-Soar plan were to provide a technological basis for manned maneuverable orbital systems; determine the optimum configuration for super-orbital missions, and demonstrate the military capability of both orbital and super-orbital vehicles.

The program office considered the Phoenix system acceptable but derived, instead, a new two-step program based on the employment of Titan III, which differed from Soltan by using two 120-inch diameter solid propellant engines. While Dyna-Soar I would encompass the "streamline" proposal, Dyna-Soar II would involve the development of a far-earth, orbital vehicle. The program office anticipated the first unmanned orbital flight in November 1964, and the first piloted flight in May 1965. The next five flights would be piloted with the purpose of accomplishing multiorbital missions. The ninth flight test, occurring in June 1966, however, would be an unmanned exploration of super-orbital velocities. The remaining nine flight tests would be piloted, with the purpose of demonstrating military missions of satellite interception and reconnaissance. The flight test program was to terminate by December 1967.

To accomplish this program, the Dyna-Soar office considered that \$162.5 million would be required for fiscal year 1962, \$211.7 million for 1963, \$167.4 million for 1964, \$168.6 million for 1965, \$99.0 million for 1966, \$21.0 million for 1967, and \$2.4 million for 1968. With \$88.2 million expended prior to fiscal year 1962, these figures would total \$921 million for the development of a manned military Dyna-Soar vehicle.[25]

On October 15, 1961, Colonel B. H. Ferer of the Dyna-Soar system staff office, USAF headquarters, requested W. E. Lamar, Deputy Director for Development in the Dyna-Soar office, to brief Dr. Brockway McMillan and a military manned spacecraft panel, convened to advise the Secretary of Defense. Mr. Lamar gave a comprehensive narrative of the history of Dyna-Soar and its current status to the assistant secretary. While Dr. McMillan approved the briefing as suitable for the spacecraft panel, he requested Mr. Lamar not to emphasize military applications at that time. The briefing to the panel followed, but Colonel Ferer once again called Lamar. The deputy for development was rescheduled to brief Dr. L. L. Kavanau, Special Assistant on Space in the Department of Defense. Dr. Kavanau appeared quite interested in the various alternatives to accelerating Dyna-Soar and finally stated that it was sensible to go directly to an orbital booster.[26]

Based on the October proposal, General Estes prepared another development plan for Dyna-Soar. This approach was presented in a series of briefings to systems command headquarters, the Air Staff, and, on November 14, to the Designated Systems Management Group.[27] The central objective was to develop a manned, maneuverable vehicle, capable of obtaining basic research data, demonstrating reentry, testing subsystems, and exploring man's military function in space. These objectives were to be achieved by adapting the Dyna-Soar glider to a Titan III booster in place of the previously approved suborbital Titan II.*

The Dyna-Soar office considered two alternate funding plans. Plan A adhered to the established $100 million ceiling for fiscal year 1962, set $156 million for 1963, and required $305.7 million from 1964 through 1967. Total development funds would amount to $653.4 million and would permit the first unmanned ground-launch by November 1964. Plan B followed the ceilings of $100 million for fiscal year 1962 and $125 million for fiscal year 1963. Under this approach, $420.2 million would be required from 1964 through 1968, totalling $736.9 million. This latter plan established April 1965 as the earliest date for the first unmanned ground-launch. Regardless of which approach was taken, the proposed program would substantially accelerate the first manned orbital flight from 1967 to 1965.[29]

On December 11, 1961, Air Force headquarters informed the systems command that the Secretary of the Air Force had agreed to accelerate the Dyna-Soar program. The suborbital phase of the old three-step program was eliminated, and the central objective was the early attainment of orbital flight, with the Titan III booster. Plan B of the November 1961 development plan was accepted, and

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*While accepting the standard space launch concept, the Department of Defense decided against the employment of a Phoenix system and, on October 13, informed Dr. McMillan that Titan III was to be the Air Force space booster.[28]

$100 million for fiscal year 1962 and $125 million for 1963 was stipulated. Finally, the Air Staff instructed the Dyna-Soar office to present a new system package program to headquarters by early March 1962.[30]

Colonel Moore set the following tentative target dates to be considered in reorienting the program: the first air-launch in July 1964; the first unmanned orbital ground-launch in February 1965; and the first manned orbital ground-launch in August 1965. The program director commented that the advancement of the program to an orbital status represented a large step toward meeting the overall objectives of Dyna-Soar.[31]

The program office then issued instructions to its contractors, the Boeing Company, the Minneapolis-Honeywell Regulator Company, and the Radio Corporation of America, pertaining to the redirected program. The tentative dates offered by Colonel Moore were to be used as guidelines for establishing attainable schedules. The Dyna-Soar glider was to be capable of completing one orbit with all flights terminating at Edwards Air Force Base, California. The system office informed the contractors that no requirements existed for maneuvering in space nor for the development of military subsystems. The contractors were to make only a minimum number of changes to the glider and the transition section in order to adapt the airframe to the Titan IIIC. To conform to budget restrictions, a serious reduction in program scope was necessary. Certain wind tunnel tests would have to be suspended. The air-launch program would consist of only 15 drops from a B-52 and would terminate in April 1965. The first two ground-launches were to be unmanned, and the remaining eight were to be piloted.[32]

On December 27, 1961, the Deputy Chief of Staff for Systems and Logistics, USAF headquarters, issued System Program Directive 4, which reiterated the program objective announced in the

November 1961 development plan. The deputy chief of staff emphasized the Air Force view that man would be required to perform missions essential to national security in space. The Dyna-Soar program would provide a vehicle which offered an economical and flexible means to return to a specific landing site, and, consequently, would fulfill a vital military need not covered in the national space program. The directive specified that Titan IIIC was to be the booster, and that only single orbits were contemplated for each ground-launch. Although Air Force headquarters chose the low funding level of Plan B, $100 million for fiscal year 1962 and $115 million for 1963, headquarters also insisted on the accelerated flight dates of Plan A.* The deputy chief of staff would accept later flight dates only if an examination by the systems command revealed the impossibility of achieving such a schedule. Lastly, a new system package program had to be completed by March 1962.[33]**

To give further legal sanction to the redirected program, Air Force headquarters, on February 21, 1962, issued an amendment to the advanced development objective, dated July 21, 1960.*** This amendment deleted references to suborbital flights and to the

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*The flight schedule of Plan A in the November 1961 development plan stipulated April 1964 for the air-launch program, November 1964 for the unmanned ground-launch, and May 1965 for the manned ground-launch.

**Major General W. A. Davis, ASD commander, protested that the March 1962 date was an arbitrary limitation and did not allow the system office enough time to reshape the program. Air Force headquarters apparently received this recommendation favorably because, on February 2, 1962, the Deputy Chief of Staff for Systems and Logistics issued an amendment to the system program directive of December 27, 1961, extending the completion date of a new system package program to the middle of May 1962.[34]

***This advanced development objective had been previously designated System Development Requirement 19, issued on July 21, 1960.

development of military subsystems. Air Force headquarters, however, did state that a reliable method for routine recovery of space vehicles would make military missions practical. The amendment further stipulated that the program was oriented to single orbital flights, with the first unmanned ground-launch occurring in November 1964.[35]

In a memorandum of February 23, 1962, Secretary McNamara officially endorsed the redirection of the Dyna-Soar program. He directed the termination of the suborbital program and the attainment of orbital flight by employment of the Titan IIIC booster. The funding level was limited to $100 million in fiscal year 1962 and $115 million in 1963. Finally, Secretary McNamara insisted on a redesignation of the Dyna-Soar program to a nomenclature more suitable for a research vehicle.[36]

By the end of February, a draft version of the system package program was completed, and, in the middle of March, the program office offered the preliminary outlines to AFSC and Air Force headquarters. The central point of this briefing was that the $115 million fiscal year 1963 ceiling would endanger the attainment of desired system reliability and would also limit the flight profile of the glider. As a result of these presentations, Air Force headquarters instructed the systems command to prepare a briefing for the Department of Defense.[37]

On April 17, officials of the Dyna-Soar office made a presentation to Dr. Harold Brown, Director of Defense for Research and Engineering. The program office wanted approval of a $12.2 million increase for fiscal year 1963 and, also, an additional $16.7 million to realize an unmanned ground-launch date of May 1965. Dr. Brown offered to give both proposals further consideration and requested the Dyna-Soar office to present alternative funding levels to meet a May or July 1965 unmanned launch date.[38]

By April 23, 1962, the system package was completed. The objective of the new Dyna-Soar program had been clearly announced by the November 1961 development plan and was reiterated in this more elaborate proposal. Dyna-Soar was a research and development program for a military test system to explore and demonstrate maneuverable reentry of a piloted orbital glider which could execute conventional landing at a preselected site. For the Dyna-Soar office, the new program represented a fundamental step towards the attainment of future piloted military space flight.

Prior to redirection in December 1961, the Dyna-Soar system office had final authority over the Step I booster being developed by the space division. Under the new program, however, the Dyna-Soar glider would only be one of the payloads for the standard space launch system, designated 624A. Titan IIIA formed the standard core and was essentially a modified Titan II with a transtage composed of an additional propulsive unit and a control module. This version of the standard launch system, although it had no assigned payload, as yet, was capable of placing 7,000 pounds into an orbit of 100 nautical miles. The Dyna-Soar glider, however, was scheduled to ride the Titan IIIC booster. This launch system was derived from the standard core with an attached first-stage of two, four-segment, solid, rocket motors, capable of delivering a total of 1,760,000 pounds of thrust.* The second and third stages were liquid propulsive units and would produce 474,000 and 100,000 pounds of thrust, respectively. Titan IIIC could place a maximum of 25,000 pounds in low-earth orbit, however, for the particular Dyna-Soar trajectory and conditions, the payload capability was 21,000 pounds.[40]

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*Late in May 1962, the Assistant Secretary McMillan requested the Dyna-Soar office to investigate the impact of employing a five-segment Titan IIIC on the program. Although this change would necessitate glider modifications amounting to $5.4 million, the program office recommended that the five-segment configuration be selected for Dyna-Soar, and command headquarters concurred on July 25.[39]

The flight test program was defined in three phases. One Dyna-Soar glider was now scheduled to accomplish 20 air-launches from a B-52C aircraft to determine glider approach and landing characteristics, obtain data on lift-to-drag ratio and flight characteristics at low supersonic velocities, and accumulate information on the operation of the glider subsystems. On four of the air-launches, the acceleration rocket would power the glider to a speed of Mach 1.4 and a height of 70,000 feet.

Following the air-launch program, two unmanned orbital launches would occur. The purpose was to verify the booster-glider system as a total vehicle for piloted flight, and demonstrate glider-design for hypersonic velocities. The Titan IIIC would propel the glider to a velocity of 24,490 feet per second, and after fulfilling its orbital mission, the vehicle would land at Edwards Air Force Base by employment of the drone-landing techniques. Eight piloted orbital flights were to follow, further exploring and defining the Dyna-Soar flight corridor.

According to the reasoning of the Dyna-Soar office, the first air-launch would occur in September 1964, with the final drop taking place in July 1965. The first unmanned ground-launch was to be conducted in May 1965, with the second unmanned flight occurring in August 1965. The first piloted flight was scheduled for November 1965 and the last manned orbital mission for the beginning of 1967. The Dyna-Soar office had hopefully attempted to obtain the earliest possible launch dates and still remain within the $115 million fiscal year 1963 ceiling set by USAF headquarters on December 27, 1961.[41]

On April 25, 1962, General Davis forwarded the system package program for the approval of AFSC headquarters. In line with Dr. Brown's request for alternative funding proposals, the Dyna-Soar office submitted a more realistic funding schedule. To meet a May 1965 schedule for the first unmanned launch, $144.8 million was required for fiscal year 1963 and $133.1 million for 1964. If the first unmanned launch was to occur in July 1965, then $127.2 million was needed for fiscal year 1963 and $133.1 million for 1964.[42*]

Following completion of the system package program, a series of presentations were made to elements of AFSC headquarters, Air Force headquarters and the Department of Defense. To remain within the $115 million fiscal year 1963 ceiling, the Dyna-Soar office was forced to reduce the development test program, thereby decreasing the reliability of the glider system and limiting the scope of the flight test program. During one of the briefings to the Department of Defense, Dr. Brown recommended significant changes to the Dyna-Soar program. Additional funds would be allotted for further development testing, and most important, the Dyna-Soar glider was to fulfill multiorbit missions.[44]

On May 14, the program office had completed a revision of its system package. The wind tunnel program was expanded. Glider and panel flutter tests were added. Work to increase the heat

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*General Davis also pointed out that the Pacific Missile Range of the Department of the Navy had issued a financial requirement of $100 million for the construction of four vessels which would be employed in the Dyna-Soar program. The ASD commander emphasized that other space programs would eventually use these facilities, and, consequently, this cost should not be fully attributed to System 620A. Pacific range officials lowered the requirement to three new ships and modification of an existing vessel, totalling $69 million. By the middle of May, Navy officials agreed that ship costs of $36 million and a total range requirement of $49 million were directly related to the Dyna-Soar program. Because of subsequent revisions to the program, range officials then submitted an increased estimate of $69 million for both the October 10, 1962 and the January 11, 1963 system package programs. The Dyna-Soar office did not concur with this figure, however, total range costs relating to System 620A were agreeably reduced to $48.888 million in May 1963.[43]

resistant ability of certain sections of the glider was contemplated. Refinement of the glider design and dynamic analysis of the air vehicle vibration were additional tasks. The program office further scheduled additional testing of the reaction control, the environmental control, and the guidance systems. A more comprehensive reliability program for the glider and the communication and tracking systems was to be inaugurated, and an analysis of a means to reduce the weight of the glider subsystems was to take place.

For the Dyna-Soar office, multiorbital missions were a logical and relatively inexpensive addition to the basic program and would probably be scheduled for the fifth or sixth ground-launch. Such a demonstration, in the opinion of the Dyna-Soar office, was a prerequisite to more extensive exploration of the military function in piloted space flight. Multiorbital missions, however, necessitated modification of the guidance system, increased reliability of all subsystems, and the addition of a de-orbiting unit.

Previously, a single-orbit Dyna-Soar mission did not require the employment of a de-orbiting system, largely because the flight profile was only an around-the-world, ballistic trajectory. The Dyna-Soar office considered two alternatives for equipping the glider with a de-orbiting ability. One possibility was to place a system in the transition section of the glider. Another approach, actually chosen, was to employ the transtage of the Titan IIIC vehicle. This fourth stage would permit accurate orbital injection of the glider and would remain attached to the transition section to provide de-orbiting propulsion.

Along with these additions to the system package program, the Dyna-Soar office submitted a new funding schedule. The requirement was $152.6 million for fiscal year 1963, $145.2 million for 1964,

$113.7 million for 1965, $78.3 million for 1966, and $17.7 million for 1967. This proposal would set the total cost for the Dyna-Soar program at $682.1 million.[45]

Before the Department of Defense acted on these revisions, the system office and Air Force headquarters had to determine a new designation for Dyna-Soar, more accurately reflecting the experimental nature of the program. In his February memorandum, Secretary of Defense McNamara directed Secretary Zuckert to replace the name "Dyna-Soar" with a numerical designation, such as the X-19. Mr. J. B. Trenholm, Jr., assistant director of the program office, requested his director for program control to derive a new nomenclature for Dyna-Soar. The assistant director added that the program office should officially request retention of "Dyna-Soar" as the popular name. Whatever the designation, Air Force headquarters required it by April.[46]

Following Air Force regulations, the director for program control reluctantly submitted ARDC form 81A, offering the designation, XJN-1 and, at the same time, requested use of "Dyna-Soar." Colonel Ferer at USAF headquarters did not concur with the XJN-1 label but offered instead XMS-1, designating experimental-manned-spacecraft. Other elements in Air Force headquarters and in the Department of Defense objected to both designations. Finally, on June 19, 1962, USAF headquarters derived and approved the designation, X-20.[47] On June 26, a Department of Defense news release explained that this new designation described the experimental character of the program.[48] By the middle of July, Air Force headquarters allowed the word, "Dyna-Soar," to stand with X-20.[49]

On July 13, 1962, USAF headquarters informed the systems command that the Secretary of Defense conditionally approved the May 14 revision of the system package program. Instead of the requested $152.6 million for fiscal year 1963, Secretary McNamara authorized $135 million and insisted that future funding would not exceed this level. He further stipulated that Dyna-Soar schedules would have to be compatible with Titan IIIC milestones and that technical confidence and data acquisition in the X-20 program would have precedence over flight schedules. Air Force headquarters then directed the program office to make appropriate changes to the system package as soon as possible.[50]

In spite of the fact that the Dyna-Soar program had been redirected, funds and approval were still lacking for System 624A, Titan III. Since the X-20 was scheduled to ride the fourth development shot of Titan IIIC, flight dates for Dyna-Soar could not be set until the Titan schedule was determined. On August 31, 1962, the space division informed the X-20 office that calendar dates for booster launchings could not be furnished until funding had been released. This was expected by November, with program development beginning in December 1962. The first Titan IIIC launch would occur 29 months later, and the fourth shot (the first, Dyna-Soar, unmanned launch) would take place 36 months after program "go-ahead."[51]

Based on this Titan IIIC scheduling assumption, the X-20 system office completed, on October 10, another system package program. Twenty air-drop tests were to be conducted from January through October 1965. Two unmanned orbital launches were to occur in November 1965 and February 1966. The first of eight piloted flights was to take place in May 1966, with a possible multiorbit launch occurring in November 1967.* The Dyna-Soar office stipulated that $135 million would be required in fiscal year 1963,

*These X-20 schedules proved compatible with the Titan III schedules, for on October 15, 1962, Air Force headquarters issued System Program Directive 9. This authorized research and development of the space booster to begin on December 1, 1962 with a total of $745.5 million from fiscal year 1962 through 1966.

$135 million in 1964, $102.78 million in 1965, $107.51 million in 1966, $66.74 million in 1967, and $10 million in 1968. The program would require $766.23 million for the development of the orbital X-20 vehicle.[52] Major General R. G. Ruegg, ASD commander, submitted this system package program to AFSC headquarters on October 12, 1962, however, it never received command endorsement.

While the X-20 office was concerned with Titan III schedules and approval of a new package program, AFSC headquarters directed a change in the organization of ASD which had possible significance for the Dyna-Soar program. On September 28, 1962, the systems command directed that the function of the ASD Field Test Office at Patrick Air Force Base, Florida, be transferred to the 6555th Aerospace Test Wing of the Ballistic Systems Division.[53]

Previously ARDC headquarters had established, on August 4, 1960, a general policy on test procedures which firmly placed control of system testing in the various project offices rather than the test centers.[54] With headquarters' approval, the Dyna-Soar office appointed a test director for the entire Category II program and directed that the Air Force Flight Test Center provide a Deputy Director for Air-Launch and the WADD Field Test Office at Patrick Air Force Base provide a Deputy Director for Ground-Launch.[55] The test centers, however, objected to giving the project offices full authority, largely because such a policy did not fully utilize their ability to conduct flight test programs. Consequently, on January 31, 1962, General Schriever rescinded the August 1960 policy and directed that, while overall authority still rested in the program offices, the centers and test wings would prepare and implement the test plans and appoint local test directors.[56] While the purpose of this new policy was to give the test centers more authority in the test program, it did not result in any significant changes to the structure of the Dyna-Soar test force. Under this new arrangement, the program office appointed a Deputy System Program Director for Test, while the flight test center provided the Air-Launch Test Force Director and the Patrick field office, the Ground-Launch Test Force Director.[57]

Throughout these changes in the Dyna-Soar test structure, the 6555th Aerospace Test Wing of the Ballistic Systems Division had authority only during the operation of the booster. With the transfer of the functions of the ASD field office to this test group, however, the aerospace wing became, in effect, the director of the orbital flight tests. This test group was responsible to the commander of BSD, who, in the instance of conflicting requirements of various assignments, would determine priorities for the operations of his test wing.[58]

In an effort to conserve program funds, the X-20 office formulated a flight test program, the "Westward-Ho" proposal, which would eliminate the necessity for the construction of several control centers and multiple flight simulators. Previous planning had located a flight control center at Edwards Air Force Base for the conduct of the air-launch tests. The ground-launch program required a launch center and a flight control center, both at Cape Canaveral, and also a recovery center at Edwards Air Force Base. "Westward-Ho" simply proposed the consolidation of the flight control centers for both the air-drop and ground-launch tests at Edwards, leaving only a launch control center at the Cape. The Air Force Flight Test Center would provide a test director for both the air-drop and orbital flight tests, who would be responsible in turn to the X-20 program office. By establishing one flight control center and employing only one flight simulator, the Dyna-Soar office estimated a savings of at least $3 million.[59]

The "Westward-Ho" logic of the X-20 office was not apparent to AFSC headquarters. On December 19, the AFSC vice commander, Lieutenant General Estes, directed the establishment of a manned space flight review group for the purpose of examining all aspects of the X-20 test program including the relationships of the various AFSC agencies. Brigadier General O. J. Glasser of the Electronic Systems Division was named chairman of this group, which was to be composed of representatives from AFSC headquarters, the aeronautical division, the space division, the missile test center and the missile development center.[60]

Colonel Moore noted that the Air Force Flight Test Center, the key agency in "Westward-Ho" had not been permitted representation at this review. Furthermore, he had offered to familiarize the committee with a presentation on the Dyna-Soar test requirement, but this proposal was rejected.[61] The significance of the coming review was not entirely clear to the X-20 program office.

General Glasser's committee formally convened on January 3 and 23 and February 5, 1963. While no decisions were made at these meetings, the members discussed several critical points of the Dyna-Soar program. Although the Test Support Panel seemed to favor the location of a single flight control center at Edwards Air Force Base, it was clear that "Westward-Ho" impinged on the interests of the Air Force Missile Development Center, the Space Systems Division, and the Air Force Missile Test Center. General Glasser, however, emphasized the central problem confronting the Dyna-Soar program: the open conflict between the Space Systems Division and the Aeronautical Systems Division for control of the only Air Force manned space program. The Organization and Management Panel offered some solutions to this problem. First, management of the program by AFSC headquarters would have to be altered. Like the Titan III program, the Dyna-Soar system should be placed under the guidance of the Deputy to the Commander for Manned Space Flight instead of the Deputy Chief of Staff for Systems. More important, the panel strongly recommended that the entire program be reassigned to the Space Systems Division. General Glasser did not favor such a radical solution but thought that a single AFSC division should be made the arbiter for both the Titan III and X-20 programs.[62]

While designating his deputy for manned space flight as a headquarters point of contact for the Dyna-Soar program, General Schriever, on May 9, 1963, altered the structure of the X-20's test force. He directed that the Space Systems Division would name the director for X-20's orbital flights, with the flight control center being located at the Satellite Test Center, Sunnyvale, California. The commander of AFSC did emphasize, however, that the Aeronautical Systems Division was responsible for the development of the X-20.[63] At the end of July, General Schriever also assigned responsibility for the air-launch program and pilot training to the space division.[64]

Although the Air Force had undertaken a manned military space study in 1961, the Department of Defense still had not determined a military space mission for the Air Force. While the 1961 study had essentially compared the Dyna-Soar glider with a SAINT II lifting body, Secretary McNamara was also interested in the military potentialities of the two-man Gemini capsule of NASA. In his February 23, 1962 memorandum, the Secretary of Defense expressed interest in participating in this program with the National Aeronautics and Space Administration for the purpose of demonstrating manned rendezvous.[65] On January 18 and 19, 1963, Secretary McNamara directed that a comparison study between the X-20 glider and the Gemini vehicle be made which would determine the more feasible approach to a military capability. He also asked for an evaluation of the Titan III and various alternative launch vehicles.[66]

A few days later, Gemini became even more significant to the Air Force, for the Department of Defense completed an agreement with the National Aeronautics and Space Administration which permitted Air Force participation in the program. A planning board, chaired by the Assistant Secretary of the Air Force for Research and Development and the Associate Administrator of NASA, was to be established for the purpose of setting the requirements of the program. The agreement stipulated that the Department of Defense would not only participate in the program but would also financially assist in the attainment of Gemini objectives.[67]

At the end of January, Major General O. J. Ritland, Deputy to the Commander for Manned Space Flight, emphasized to the commanders of ASD and SSD that Secretary McNamara intended to focus on the X-20, Gemini, and Titan III programs with the ultimate objective of developing a manned military space system. General Ritland warned that once a decision was made it would be difficult for the Air Force to alter it. Consequently, command headquarters, the space division, and the aeronautical division would have to prepare a comprehensive response to the secretary's request. General Ritland then gave the Space Systems Division the responsibility for providing statements of the Air Force manned space mission and for defining space system requirements, tests, and operations.[68]

By the end of February 1963, AFSC headquarters had compiled a position paper on the X-20 program. Six alternative programs were considered: maintain the present program, reorient to a lower budget through fiscal year 1964, accelerate the flight test program, reinstate a suborbital phase, expand the program further exploring technological and military objectives, and, finally, terminate the X-20 program. The conclusion of command headquarters was to continue the present X-20 and Titan III programs.[69]

Early in March General LeMay offered his thoughts on the coming review by the Secretary of the Air Force. He firmly stated that continuation of Titan III was absolutely necessary, and most important, the current X-20 program should definitely proceed. The Air Force Chief of Staff emphasized that the Dyna-Soar vehicle would provide major extensions to areas of technology important to the development of future military systems and, consequently, the Air Force should not consider termination of the X-20 program or delay of schedules for the approval of an alternative space program. General LeMay insisted that the purpose of Air Force participation in the Gemini program was limited to obtaining experience and information concerning manned space flight. The Chief of Staff underlined that the interest of the Air Force in the NASA program was strictly on the basis of an effort in addition to the Dyna-Soar program.[70]

After hearing presentations of the X-20, Gemini, and Titan III programs in the middle of March, Secretary McNamara reached several conclusions which seemed to reverse his previous position on the experimental nature of the Dyna-Soar program. He stated that the Air Force had been placing too much emphasis on controlled reentry when it did not have any real objectives for orbital flight. Rather, the sequence should be the missions which could be performed in orbit, the methods to accomplish them, and only then the most feasible approach to reentry. Dr. Brown, however, pointed out that the Air Force could not detail orbital missions unless it could perform controlled reentry. Furthermore, the Director of Defense for Research and Engineering stated that the widest lateral mobility, such as possessed by the X-20, during landing was necessary in performing military missions. Dr. McMillan surmised that Secretary McNamara did not favor immediate termination of the X-20 program.[71] Secretary McNamara did request, however, further comparison between Dyna-Soar and Gemini in the light of four military missions: satellite inspection, satellite defense, reconnaissance in space, and the orbiting of offensive weapon systems.[72]

On May 10, 1963, a committee composed of officials from the aeronautical and space divisions completed their response to Secretary McNamara's direction. The committee was aware that the Dyna-Soar glider had sufficient payload capacity for testing a large number of military components and that the X-20's demonstration of flexible reentry would be an important result of the flight test program. Concerning Gemini, the committee also recognized that this program would enhance knowledge relating to maneuverability during orbit and consequently recommended the incorporation of a series of experiments leading to the testing of military subsystems. Further in the future both vehicles could be adapted to serve as test craft for military subsystems; however, neither could, without modification, become a fully qualified weapon system for any of the missions specified by Secretary McNamara. With the employment of Titan III instead of Titan II and the incorporation of a mission module, this Gemini system could provide greater orbital maneuverability and payload capacity than the X-20. The Dyna-Soar vehicle, however, would provide greater flexibility during reentry and, unlike Gemini, could return the military subsystems to Earth for examination and reuse.[73]

General Ritland forwarded this report to Air Force headquarters a few days later. The deputy for manned space flight recommended that the X-20 program be continued because of the contribution that a high lift-to-drag ratio reentry vehicle could make for possible military missions. Air Force participation in the Gemini program, however, should be confined to establishing a small field office at the NASA Manned Space Center and seeing that military experiments were part of the program.[74]

While the Department of Defense had not made a final determination concerning the X-20 and Gemini, General Estes cautioned the Dyna-Soar office at the end of June that the

Secretary of Defense was still studying the military potential of both approaches. The vice commander stated that the system office had to maintain a position which would permit continuation of the program while at the same time restricting contractor actions to assure minimum liability in event of cancellation.[75]

While the X-20 and Gemini approaches to orbital flight were under examination, the Dyna-Soar office was also confronted with an adjustment to the program because of a pending budget reduction. In November 1962, it had been apparent that the Department of Defense was considering restriction of fiscal year 1963 and 1964 funds to $130 million and $125 million instead of the previously stipulated level of $135 million for both years.[76] Colonel Moore pointed out to AFSC headquarters that only through aggressive efforts would $135 million be sufficient for fiscal year 1963 and any proposed reduction would be based on a lack of understanding of the Dyna-Soar requirements. Furthermore, an increase in fiscal year 1964 funds was necessary, raising the figure to $147.652 million.[77] Later, the system office informed General LeMay that schedules could not be maintained if funding were reduced and that $135 million and $145 million would be required for fiscal years 1963 and 1964.[78]

During March 1963, the X-20 office prepared four funding alternatives, which General Estes submitted to Air Force headquarters at the end of the month. The most desirable approach was to maintain the program schedules as offered in the October 10, 1962 system package program by increasing the funding. The X-20 office estimated that $135 million was required for fiscal year 1963, $145 million for 1964, and $114 million for 1965, which gave a total program cost of $795 million. The second alternative was to authorize a ceiling of $792 million, with $135 million allotted for 1963, $135 million for 1964, and $120 million for 1965. This reduction could be accomplished by deferring the multiorbit flight date by six months. The third option required $130 million for 1963, $135 million for 1964, and $130 million for 1965, with a program total of $807 million. Such a funding arrangement would delay the entire program by two months and defer the multiorbit flight from the fifth to the seventh ground-launch. The least desirable approach was to delay the entire program by six months, authorizing $130 million for 1963, $125 million for 1964, and $125 million for 1965. Under this alternative, the program would total $828 million.[79]

On April 12, 1963, Air Force headquarters accepted the third alternative. A funding level of $130 million was established for 1963 and the system office was directed to plan for $135 million in 1964. Headquarters stipulated that program schedules could not be delayed by more than two months and that a new system package program had to be submitted by May 20.[80]

On January 15, 1963, the Dyna-Soar office had completed a tentative package program which included the same funding and flight schedules as the October 10, 1962 proposal. The central difference was that the latter program incorporated the "Westward-Ho" proposal.[81] This system package program, however, was not submitted to AFSC headquarters for approval. In accordance with the April 12, 1963 instruction, the X-20 office completed another system package program on May 6 which was distributed to the various program participants for their comments. On May 9, however, General Schriever assigned the orbital test responsibility to the Space Systems Division, and, consequently, AFSC headquarters again instructed the Dyna-Soar office to revise the X-20's system package program by May 13.[82]

In the May 13 system package program, the X-20 office estimated that $130 million was required for fiscal year 1963, $135 million for 1964, $130 million for 1965, $110 million for 1966, and

$73 million for 1967. The air-launch program was to extend from March 1965 through January 1966, with the two unmanned ground-launches occurring in January and April 1966. The first piloted flight would take place in July 1966 with the first multiorbit flight occurring in May 1967. The eighth and final piloted flight was to be conducted in November 1967.[83] Brigadier General D. M. Jones, acting commander of ASD, informed AFSC headquarters that there had been insufficient time to incorporate the details of the new test organization in the program package. Furthermore, a funding level of $130 million and $135 million for fiscal years 1963 and 1964 could delay Dyna-Soar flights by more than the two months anticipated in the April 12 direction of USAF headquarters.[84]

On May 27, another system package program was completed. The same funding rates as the May 13 proposal were retained but the flight schedule was revised in order to conform with firm contractor estimates. The air-launch program was to extend from May 1965 through May 1966. The two unmanned launches were to take place in January and April 1966, and the first piloted launch was to occur in July 1966. Recognizing the necessity for a four month interval between single and multiorbit flights, the X-20 office set August instead of May 1967 for the first multiorbit launch. The Dyna-Soar flight test program was to terminate in February 1968 with the eighth orbital launch.[85]

The Secretary of the Air Force gave his approval to this system package program on June 8, 1963; however, the Department of Defense did not accept the recommended funding. On July 3, AFSC headquarters informed the Dyna-Soar office that attempts to secure additional funding had failed. The funding level for fiscal year 1964 was $125 million.[86] By September it was clear to the Dyna-Soar office that the consequence of this reduced funding level would be to delay multiorbital flight from the seventh to the ninth ground-launch.[87]

While final approval by the Department of Defense of the Dyna-Soar system package was still pending in the middle of 1963, the impact of the December 1961 redirection on the Dyna-Soar program was apparent. The first Dyna-Soar development plan of October 1957 had definite military objectives leading to the development of orbital reconnaissance and bombardment vehicles. In April 1959, Dr. York, then Director of Defense for Research and Engineering, altered these goals and placed major emphasis on the development of a suborbital research vehicle. In spite of intensive comparative studies with manned SAINT and Gemini vehicles, the central purpose, as established by Dr. York, had not changed. While the system program directive of December 1961 and Secretary McNamara's memorandum of February 1962 elevated Dyna-Soar to an orbital vehicle, the glider was officially described as an experimental system.

Conceivably the redirected program could appear as a reversal of the three-step approach which was aimed at the development of a suborbital system, an orbital glider with interim military ability, and an operational weapon system. Yet, under this old development plan, the real Dyna-Soar program had only consisted of a glider which would perform suborbital flight. Consequently, Department of Defense sanction of the new program marked an advancement over the three-step approach in that orbital and even multiorbital flights of the X-20 glider were now established objectives of Dyna-Soar.

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CHAPTER V

CANCELLATION

In 1963 the Department of Defense was again seriously questioning the necessity for the Dyna-Soar program. It appeared that the alternative for the X-20 had been severely narrowed: direct the program towards achieving military goals or terminate it in lieu of another approach to a manned military space system. During the Phase Alpha studies of 1960 and the Manned Military Space Capability Vehicle studies of 1961, the reentry approach of the Dyna-Soar glider was critically compared with other reentry proposals and systems. On these two occasions, both the Air Force and the Department of Defense deemed the Dyna-Soar as the most feasible. The X-20 program, however, was not as fortunate in the 1963 evaluations.

In December 1961, Air Force headquarters had eliminated suborbital launches of the Dyna-Soar vehicle and had directed the early attainment of orbital flight. The objectives were to obtain research data on maneuverable reentry and demonstrate conventional landing at a preselected site.[1] Secretary of Defense Robert S. McNamara later confirmed this redirection and identified the purposes of the military space program. He stated that the establishment of the necessary technology and experience for manned space missions were the immediate goals. The Secretary placed emphasis on acquiring the ability to rendezvous with uncooperative targets, to maneuver during orbital flight and reentry, to achieve precise recovery, and to reuse the vehicles with minimum refurbishment. In order to realize these ends, Secretary McNamara offered three programs. The orbital research Dyna-Soar program would provide a necessary technological basis. A cooperative effort with the National Aeronautics and Space Administration in its Gemini program would give experience in manned rendezvous. Lastly the defense secretary stated that a manned space laboratory to conduct sustained tests of military systems could be useful.[2]

It was not until January 1963 that Secretary McNamara took another significant step in defining a military space program. He directed a comparison between the Dyna-Soar program and the Gemini program of NASA to determine which would be of more military value.[3] Gemini became even more important a few days later when the Department of Defense completed an agreement with the national aeronautics administration for Air Force participation. Following a review in the middle of March of the Dyna-Soar program, Secretary McNamara further clarified his directions concerning the Gemini and X-20 study. He considered that the Air Force had placed too much emphasis on controlled reentry and not on the missions which could be performed in orbit. Inspection, reconnaissance, defense of space vehicles, and the introduction of offensive weapons in space were all significant. He suggested that the Air Force take as long as six months to determine the most practicable test vehicle for these military space missions. The Secretary of Defense then suggested that a space station serviced by a ferry vehicle could be the most feasible approach.[4] Air Force headquarters directed the Air Force Systems Command to organize studies concerning X-20 and Gemini contributions to these four missions.[5]

By May 10, a committee, under the leadership of the Space Systems Division and composed of representatives from the Aerospace Corporation, Air Force Systems Command headquarters, and the Aeronautical Systems Division, completed a comparison of Gemini and the X-20. The committee considered that the current X-20 program could be rapidly, and with relative economy, adapted for testing of military subsystems and military operations. There were several reasons. The Dyna-Soar glider had a payload volume of 75 cubic feet, sufficient power, and enough cooling capacity to accommodate subsystems required for military missions. Furthermore, the orbital duration of the vehicle could be extended to 24 hours or longer.

Concerning reconnaissance missions, the committee thought that the X-20 program could develop low, orbital, operational techniques and ground recognition ability. The research data from the program would also be applicable for the verification of the feasibility, design, and employment of glide bombs. The fact that the X-20 would develop maneuvering techniques and quick return methods made the program valuable for the development of satellite defensive missions. Since deceleration occurred slowly during lifting reentry, such an approach would provide a safe physiological environment for transfer of personnel from space stations and for other logistical missions. Lastly, significant information for the development of future maneuvering reentry spacecraft would be obtained from the X-20 program.

The committee then detailed the necessary modifications to the X-20 glider in order to allow the incorporation of either reconnaissance or satellite inspection equipment. A test program of four X-20A flights, six reorientation flights for testing reconnaissance subsystems, and two demonstration flights, would total $206 million from fiscal years 1964 through 1968. The same type of program, this time for the testing and demonstration of inspection subsystems, would total $228 million.[6]

In contrast, the technology being developed by the Gemini program of NASA related to the ability to rendezvous and orbit for long durations. The committee estimated that to incorporate a series of military experiments into the current NASA program with only minor equipment and operational flight changes would total about $16.1 million from fiscal years 1964 through 1966. If the

Department of Defense conducted two Gemini launches and employed the same booster as NASA, the Titan II, the cost for inspection and reconnaissance experiments would total $129 million from fiscal years 1964 through 1967. If six Department of Defense flights were conducted, the total would be $458 million. The committee then considered a series of Gemini launches conducted by the Department of Defense, this time using the Titan IIIC. Because the 5,000 pound Gemini capsule only had a limited payload capacity of 10 cubic feet, the committee considered the addition of a mission module, which would have to be discarded in space, to the Gemini capsule. The largest test module which was considered had a volume of 700 cubic feet. The committee then examined the applicability of such a test system to reconnaissance and inspection missions. Considering a six flight program beginning in July 1966, with the following flights at five month intervals, an inspection test flight program would total $509 million and a reconnaissance flight test program would cost $474 million.[7]

The committee concluded that the main advantage of the Gemini vehicle was that it was lighter than the X-20 and consequently could carry more fuel for orbital maneuverability or have a larger payload. The inherent advantage of the X-20 was its maneuverability during reentry which meant that it could land quicker and with more landing site options. The committee recommended that a series of military experiments should be implemented in the NASA Gemini program and that additional flights of the X-20 might be warranted. Both systems could be modified to perform reconnaissance, inspection, satellite defense, and logistical missions; however, neither would directly provide a means of introducing offensive weapons into earth orbit.[8]

On May 22 Major General O. J. Ritland, Deputy to the Commander for Manned Space Flight, AFSC headquarters, forwarded the report to Air Force headquarters with the recommendation that the X-20 program be continued because of the contribution a high lift-to-drag ratio vehicle could make to future military systems. Air Force participation in the Gemini program should be limited to incorporating a series of military experiments into the NASA program.[9]* A few weeks later, Brockway McMillan, the Assistant Secretary of the Air Force for Research and Development, summarized the report in a memorandum to the Secretary of Defense. The assistant secretary recommended that the X-20 program be energetically continued. He suggested that further examination of the military applications of the X-20 and Gemini be extended under various study programs.[10]

At the request of AFSC headquarters, the program office then completed a study concerning the use of the X-20 in anti-satellite missions. The Dyna-Soar office proposed an X-20B which would have an interim operational capability of satellite inspection and negation. The program office suggested that the last six flights of the current X-20A program be altered to carry inspection sensors and additional fuel for space maneuver demonstration. Two additional flights would be added to demonstrate an interim operational capability. This would necessitate a weight reduction to the X-20 glider of 700 pounds which could be achieved through a series of design changes. Such a program would total $227 million from fiscal years 1964 through 1968. To conduct a 50 flight operational program following the completion of the two demonstration flights would cost $1.229 billion from fiscal years 1965 through 1972.[11]

Near the end of June 1963, the Space Systems Division requested the X-20 office to conduct, as part of the 706 Phase 0 studies, an analysis which would show the capability of the Dyna-Soar vehicle

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*Secretary McNamara approved the incorporation of Air Force experiments in the NASA Gemini program on June 20, 1963.

and modified versions to fulfill satellite inspection missions.[12] With the assistance of the Boeing Company, the system contractor, the Minneapolis-Honeywell Regulator Company, an associate contractor, and the Air Force Aerospace Medical Division, the Dyna-Soar office completed its report by the middle of November. This study offered an inspection vehicle, the X-20X, which could have provisions for a one or two-man crew, permit orbital flight for 14 days, and be capable of inspecting targets as high as 1,000 nautical miles. The Dyna-Soar office estimated a first flight date of the X-20X in September 1967 and a probable funding requirement, depending upon the extent of modifications, ranging from $324 million to $364.2 million for fiscal years 1965 through 1971.[13]

Since the completion of the Step IIA and IIB studies by Boeing in June 1962, the Dyna-Soar office had on several occasions requested funds for intensive military application studies, and, on July 8, 1963 W. E. Lamar, Director of the X-20 Engineering Office, reiterated this request during a presentation to the Secretary of the Air Force, E. M. Zuckert.[14] A few days later, Secretary Zuckert, attending a meeting of the Designated Systems Management Group, directed studies of the operational applications of Dyna-Soar. He stated that the X-20 program would probably prove to be invaluable to the national military space program.[15]

Before the purpose of these studies was clarified, the future of the Dyna-Soar became tied to a projected space station program. On July 22 Vice President Lyndon B. Johnson raised the question of the importance of space stations to national security and requested the Secretary of Defense to prepare a statement on this subject.[16] Secretary McNamara replied a few days later and stressed a factor which the Air Force now had to consider: multi-manned orbital flights of long duration. The Secretary outlined some premises upon which America's manned military space program was to be based.

He stated that the investigation of the military role in space was important to national security. Because there was no clearly defined military space mission, present efforts should be directed towards the establishment of the necessary technological base and experience in the event that such missions were determined. The Secretary of Defense pointed out that Air Force participation in the Gemini program would provide much of this technological base. He considered that an orbital space station could prove useful in conducting experiments to improve capability in every type of military mission. Such a system could even evolve into an operational military vehicle. Secretary McNamara informed Vice President Johnson that he hoped to have the characteristics of an orbital space station delineated by early 1964.[17]

In September a subcommittee of the President's Scientific Advisory Committee Space Vehicle Panel was formed to review the available data relative to a manned orbiting station. The President's Office of Science and Technology requested the Air Force to brief the subcommittee on possible military space missions, biomedical experiments which could be performed in space, and the capability of Gemini, Apollo, and the X-20 vehicles to execute these possible future requirements.[18]

Additional instructions concerning the briefing to the President's Scientific Advisory Committee were relayed from the Director of Defense for Research and Engineering by Air Force headquarters to the Aeronautical Systems Division. Considerations such as modifications of the X-20 and discussion of an orbital space station should be emphasized. Air Force headquarters pointed out that the Department of Defense was not convinced that an orbital space station was needed. Rather a study of the requirements to test military equipment in space was necessary to answer questions such as equipment characteristics and the usefulness of man in space.[19]

A few days later Dr. Lester Lees, chairman of the subcommittee, gave additional information to Mr. Lamar about the coming presentation. Emphasis was to be on specific, meaningful experiments which the Air Force could conduct with either Gemini, Apollo, or the X-20, in order to provide a technological basis for future military space missions. Dr. Lees pointed out that it was necessary to convince a number of governmental officials that military man had a definite mission in space. The usual arguments for manned space flight such as decision-making and flexibility were inadequate. The subcommittee chairman stated that more specific reasons must be given or it was unlikely that extensive funds would be available for the development of manned space systems.[20]

The briefings to the President's Scientific Advisory Committee on October 10 essentially covered the findings concerning Gemini and the X-20 in the earlier May 10 report of the Air Force to Secretary McNamara. More detail, however, was presented on the use of the X-20 as a shuttle vehicle capable of rendezvous and docking. A configuration of the X-20 with an orbital development laboratory was also considered.[21] After completion of the presentations, Dr. Lees commented to Mr. Lamar that although he had previously been against the continuation of the Dyna-Soar program he now saw a definite need for the X-20. He would no longer oppose the program.[22]

By the end of October the purposes of the Dyna-Soar capability studies, which Secretary Zuckert had agreed to in July, were clarified. Following the instructions of Air Force headquarters, Lieutenant General H. M. Estes, AFSC Vice Commander, informed Major General R. G. Ruegg, ASD commander, that the purpose of the first study was to formulate a program of military space experiments involving only engineering changes to the X-20's subsystems. The Vice Commander added that this program of experiments should be compared to a similar one employing the Gemini vehicle to insure that the Dyna-Soar approach offered the most economical and effective means of accomplishment. A second study would integrate the findings of various other studies and establish a series of mission models for reconnaissance, surveillance, satellite inspection, and also logistical support of a space station. A third study was to examine the future operational potential of reentry vehicles having a lift-to-drag ratio greater than the X-20. A final study would examine the economic implications of various modes of recovering space vehicles from near-earth orbit.[23] At the end of November, AFSC headquarters informed the X-20 office that Air Force headquarters had approved all but the second proposal which had just been submitted.[24] *

Early in October 1963, General B. A. Schriever, AFSC Commander, informed ASD and SSD that the Secretary of Defense intended to visit the Martin Company facilities at Denver, Colorado, to receive briefings on the status of the X-20 and Titan III programs.[25] Colonel W. L. Moore, X-20 program director, later noted that the directions were somewhat in error because it became apparent during these presentations that Secretary McNamara desired far more than a status briefing.[26]

Prior to these briefings, there were numerous indications that the future of the Dyna-Soar program was uncertain. Several X-20 displays and activities had been planned for the Air Force Association convention which was to be held in the middle of September. One of the proposed events involved the continuous showing of a brief film on the nature and objectives of the Dyna-Soar program. Although this film was an updated version of

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*On December 16 AFSC headquarters canceled the first two studies, both of which dealt directly with the Dyna-Soar program.

one previously unclassified and released, the Office of the Secretary of Defense refused its clearance for the convention.[27] Furthermore, neither Dr. A. C. Hall, Deputy Director for Space in the Office of the Director of Defense for Research and Engineering, nor Dr. A. H. Flax, now Assistant Secretary of the Air Force Research and Development, indicated agreement to a briefing by the Air Force Plant Representative at Boeing on the necessity for manned military space flight.[28] It was reported that some X-20 Boeing officials became concerned over the future of the program after this visit.[29] In addition, the Director of Defense for Research and Engineering, Dr. Harold Brown, had not approved the release of funds for X-20's range requirements. The AFSC Vice Commander was concerned and considered that the range operational date of October 1965 for the Dyna-Soar program was certainly in jeopardy.[30] Lastly, Dr. Brown, in a speech before the United Aircraft Corporate Systems Center at Farmington, Connecticut, appeared critical of the Air Force manned space programs. He stated that both the Gemini and X-20 programs had very limited ability to answer the question of what man could do in space. Unless an affirmative answer were found, there would be no successor to these programs.[31]

A few days later, on October 23, Secretary McNamara accompanied by R. L. Gilpatric, Deputy Secretary of Defense; Harold Brown, and Brockway McMillan, now Under Secretary of the Air Force, were briefed by Titan III and X-20's officials. At the conclusion of his presentation, Colonel Moore stated that it would be desirable to have the Department of Defense publicly state its confidence in the Dyna-Soar program. The X-20's director then asked if there were any questions.[32]

Both Secretary McNamara and Dr. Brown asked a series of questions directed towards obtaining information on the necessity of manned military space systems. Secretary McNamara stated that the X-20 office had been authorized to study this problem since

March 1963. He emphasized that he considered this the most important part of the X-20 program. The Secretary of Defense wanted to know what was planned for the Dyna-Soar program after maneuverable reentry had been demonstrated. He insisted that he could not justify the expenditure of about $1 billion for a program which had no ultimate purpose. He was not interested in further expenditures until he had an understanding of the possible space missions. Only then would the department give a vote of confidence to the X-20 program. Secretary McNamara then directed Dr. McMillan to get the answers.[33]

Some of the participants arrived at varying conclusions concerning the reaction of Secretary McNamara to the briefing. Mr. J. H. Goldie, Boeing's X-20 chief engineer, thought that the Secretary of Defense did not appear to be firmly against the X-20 nor in favor of Gemini. Rather, Secretary McNamara seemed willing to allow the Air Force to use the X-20 as a test craft and a military system if a case could be adequately made for a manned military space system.[34] Mr. Lamar concluded that the Secretary of Defense was not satisfied with the response and that "drastic consequences" were likely if an adequate reply were not made.[35] Colonel Moore prophetically stated that Secretary McNamara "probably will not ask us again."[36]

Just as serious as Secretary McNamara's reception of the X-20 briefing was the refusal of the Department of Defense to sanction a revision of the system package program. From May through September 1963, several changes involving the test organization and funding were made to the X-20 program. On May 9, 1963, General Schriever had directed that the Dyna-Soar orbital test program be assigned to the Space Systems Division. The AFSC Commander further ordered that the mission control center be located at the Satellite Test Center in Sunnyvale, California, instead of the Air Force Missile Test Center.[37] The May 27, 1963 system package program reflected this change in the test program and registered a requirement of $135 million for fiscal year 1964.

While Air Force headquarters approved this system package program in June, the Department of Defense would only allow $125 million for fiscal year 1964. On July 3 the Air Force Systems Command headquarters informed the X-20 office that attempts to obtain the higher funding level had failed.[38] The Director of Defense for Research and Engineering considered that the primary purpose of the program was to acquire data on maneuverable reentry. Incorporation of multiorbital flight was only of secondary importance, and the X-20 office could defer the first multiorbital flight date to remain within budget limitations.[39] AFSC headquarters then directed that a revised system package program be completed by early September.[40] Before this could be accomplished, General Schriever transferred not only orbital test direction to the space division but also responsibility for the air-drop program and the training of X-20 pilots.[41] These additional changes would also have to be incorporated into the revised system package program.

The September 3 program package presented the adjusted financial estimates and flight schedules. Considering that $125 million had been authorized for fiscal year 1964 and a total of $339.20 million had previously been expended, the program office estimated that $139 million would be required for 1965, $135.12 million for 1966, $93.85 million for 1967, $31.85 million for 1968, and $3 million for 1969. The total cost for the Dyna-Soar program would amount to $867.02 million. The reduction of fiscal year 1964 funds was absorbed by delaying the necessary modifications for multiorbital flight and deferring the date of the ninth ground-launch (the first multiorbital flight) from August 1967 to December 1967. The 20 air-launches were to occur from May 1965 through May 1966, and the two unmanned ground-launches were to take place in January 1966 and April 1966. The first piloted ground-launch was to occur in July 1966, and the last piloted flight was to be conducted in February 1968.[42]

Soon after the issuing of this program package there was some concern over the expense involved in locating the mission control center at Sunnyvale. Colonel Moore estimated that this relocation would increase program costs by several million dollars.[43] Major General L. I. Davis, a special assistant to the AFSC Vice Commander, supported this argument by stating to General Schriever that many of the functions necessary for launch control were also necessary for mission control. It would be less expensive to keep both control centers at the Air Force Missile Test Center.[44]

At the request of AFSC headquarters, the X-20 office forwarded, on September 23, a revision of the September 3 system package program which detailed adjustments to program costs if the mission control center remained at Cape Canaveral. The X-20 office estimated that $138.13 million would be required for fiscal year 1965, $130.66 million for 1966, $88.34 million for 1967 and $31.09 million for 1968. The total program cost would amount to $853.23 million instead of the previously estimated $867.02 million.[45] On October 17, 1963, AFSC headquarters forwarded the system package program to the Air Staff, informing them that it was more feasible to locate the mission control center at the missile test center.[46] This program package did not receive the endorsement of either headquarters. As late as November 21, the X-20's assistant director, J. B. Trenholm, reminded AFSC headquarters that it would be beneficial to the program if the systems command would approve of the program package.[47]

It had been reported that, on the day following the October 23, 1963 briefing to Secretary McNamara, Dr. Brown had offered a manned orbiting laboratory program to the Air Force in exchange for Air Force agreement to terminate the X-20 program. General C. E. LeMay, the Air Force Chief of Staff, did not agree and directed an Air Force group to prepare a rebuttal to such a proposal.[48] Previously, in August, Dr. Brown had approved an Air Force request to conduct a study of an orbital space station. He authorized the expenditure of $1 million for fiscal year 1964. The Air Force was to focus on the reconnaissance mission with the objective of assessing the utility of man for military purposes in space. In determining the characteristics of such a station, the Air Force should consider the use of such programs as the X-15, the X-20, Mercury, Gemini, and Apollo. This study had to be concluded by early 1964.[49]

Before the completion of this space station study, however, Dr. Brown recommended a program for such an effort to Secretary McNamara in a November 14, 1963 memorandum. The Director of Defense for Research and Engineering analyzed varying sizes of space station systems which would incorporate either the Gemini or Apollo capsules as ferry vehicles and would employ either the Titan II, the Titan IIIC, or the Saturn IB booster. Two of the approaches were suitable. One would involve the use of the Lunar Excursion Module (LEM) adapter as a space station and the Saturn IB as the booster. The Apollo command module and the Titan IIIC would perform the logistics function. Dr. Brown estimated that this approach would cost $1.286 billion from fiscal years 1964 through 1969. The first manned ferry launch could take place in late 1966, and active station tests could be conducted by late 1967.

The alternative which the Director of Defense for Research and Engineering preferred was to develop a space station with provisions for four men, use the Gemini capsule as a ferry vehicle, and separately launch both the station and capsule with a Titan IIIC booster. From fiscal years 1964 through 1968, this approach would total $983 million. The first manned ferry launch could occur in the middle of 1966, and active space station tests could begin in the middle of 1967.

Dr. Brown, however, was concerned because both of the recommended approaches would employ primitive landing methods, and, consequently, he suggested the development of a low lift-to-drag ratio vehicle which could perform maneuverable reentry and conventional landing. The Director of Defense for Research and Engineering suggested that models of such a craft be tested in the Aerothermodynamic Structural Systems Environmental Test program (ASSET) during 1964 and 1965, and he estimated that an improved ferry vehicle could be available for later station tests. The total for this more sophisticated vehicle program would amount to $443 million for fiscal years 1964 through 1968.

Dr. Brown's recommendation to Secretary McNamara was brief: cancel the X-20 program and initiate the Gemini approach to a manned military space station. Management of the Gemini program should be transferred from NASA to the Department of Defense by October 1965.[50]

Discussions between National Aeronautics and Space Administration and Department of Defense officials made it clear that the space agency would agree to a coordinated military space program, but it was not prepared to support a space station program. Instead NASA suggested a program for an orbiting military laboratory which did not involve ferrying, docking, and resupplying. On November 30 Dr. Brown, in another memorandum to Secretary McNamara, analyzed an approach more agreeable to NASA. This alternative would involve the orbiting by a Titan IIIC booster of a Gemini capsule and a 1,500 cubic foot test module, capable of supporting two to four men for 30 days. Dr. Brown maintained that such an approach could easily be converted into the Gemini alternative he had recommended on November 14. This simplified approach would total $730 million from fiscal year 1964 through 1968, and the manned orbital test program could be conducted in late 1967. Dr. Brown, however, advised the Secretary of Defense that the space station proposal of November 14 was still the most feasible and should be initiated.[51]

While NASA had suggested a simplified Gemini approach, it by no means concurred with the proposed termination of the X-20 program. The Associate Administrator for Advanced Research and Technology, Dr. R. L. Bisplinghoff, pointed out that advanced flight system studies had repeatedly shown the importance of developing the technology of maneuverable hypersonic vehicles with high-temperature, radiation-cooled metal structures. Test facilities were unable to simulate this lifting reentry environment, and, consequently, X-20 flights were necessary to provide such data. NASA had always supported the Dyna-Soar program and should it be canceled the space agency would have to initiate a substitute program.[52]

In order to achieve the objective of obtaining data on reentry, Dr. Bisplinghoff recommended some changes to the Dyna-Soar program. After completion of an adequate air-drop program and a satisfactory unmanned ground-launch flight, a piloted orbital flight should be conducted.[53] Dr. Brown requested Dr. Flax to examine such an alternative for the X-20.[54] With the assistance of the X-20 program office and AFSC headquarters, Dr. Flax completed his reply on December 4. He estimated that such a curtailed program would reduce the total cost by $174.4 million through fiscal year 1969. He pointed out, however, that such an approach would result in the loss of technical data which would be disproportionate to the financial savings.[55]

On the same day, in another memorandum to the Secretary of the Air Force, Dr. Flax firmly disagreed with the recommendations of

Dr. Brown's November 14 memorandum. The Assistant Secretary pointed out that the X-20 had not been given serious consideration as an element in any of the space station proposals. He emphasized that major modifications were necessary to both the Gemini and the X-20 if either were to be employed in an orbital station program. Furthermore, the Dyna-Soar approach possessed several advantages: the vehicle could make emergency landings without the costly deployment of air and sea elements and there would be a more tolerable force of vehicle deceleration during reentry. Dr. Flax continued by emphasizing the importance of the X-20 program. Its technology not only supported the development of reentry vehicles, including Dr. Brown's improved ferry vehicle, but also an entire class of hypersonic winged-vehicles. Since about $400 million had already been expended on the X-20 program, the Assistant Secretary severely questioned the proposal to cancel Dyna-Soar and initiate a new program with similar objectives. While he endorsed the purposes of the space station program, Dr. Flax believed that the decision to begin such a program was independent of the question to terminate the X-20.[56]

On the same day, Secretary of the Air Force Zuckert forwarded Dr. Flax's memorandum to Secretary of Defense McNamara with the statement that it represented the best technical advice available in the Air Force. The Secretary of the Air Force added that both he and Dr. Brockway McMillan were in accord with Dr. Flax's position. Secretary Zuckert further stated that he did not wish to see the Air Force abandon a program such as Dyna-Soar and start a new program which perhaps had been projected upon optimistic schedules and costs.[57]

As an Air Force reply to Dr. Brown's November 14 memorandum, Major General J. K. Hester, the Assistant Vice Chief of Staff, suggested to the Secretary of the Air Force several alternatives for varying sizes of space stations, all of which employed the X-20 vehicle. The first alternative offered an extended X-20 transition section which would provide a module of 700 cubic feet. This would be a two-man station employing an X-20 launched by a Titan IIIC. The second approach comprised a separately launched two-room station by the Titan II. This would have 1,000 cubic feet of volume and would be serviced by an X-20 shuttle vehicle boosted with a Titan IIIC. The third alternative, recommended by General Hester as the most feasible, involved a five-man station launched by Titan IIIC and capable of orbiting for one year. This approach would require $978.4 million from fiscal years 1964 through 1969 for the development of a space station and the X-20 ferry vehicle. The Assistant Vice Chief of Staff considered that the first space station launch could take place by the middle of 1967. With an X-20 approach to a space station program, it was not necessary to have a separate program for an improved ferry vehicle. Rather, only an annual funding level of $6.4 million for the ASSET program was necessary to advance space technology. General Hester therefore recommended the initiation of a space station program employing the X-20 and, if economy were essential, the cancellation of the Gemini program.[58]

On the next day, Secretary Zuckert forwarded General Hester's memorandum to Secretary McNamara. The Air Force Secretary stated that the Air Staff study clearly indicated that there was no definite reason for omitting the X-20 from consideration as a reentry vehicle for an orbital space station or orbital laboratory program. This was particularly important because of safety and cost advantages which the X-20 offered for long duration orbital missions. Secretary Zuckert believed that the X-20's alternative deserved serious consideration.[59]

On December 8 a rumor circulated in Air Force headquarters that the Defense Department had reduced X-20's fiscal year 1964 funds from $125 million to $80 million and had not allocated any money for fiscal year 1965.[60] The next day defense officials conferred with President Johnson. Apparently, Secretary McNamara recommended the termination of Dyna-Soar, and the President agreed.[61] On December 10 the Secretary of Defense announced the cancellation of the X-20 project. The program had been reviewed, alternatives studied, and the decision made. In its place would be a manned orbital laboratory (the NASA proposal which Dr. Brown explained in his November 30, 1963 memorandum). The Secretary of Defense also stated that there would be an expanded ASSET program (the improved ferry vehicle program which Dr. Brown offered in his November 14 memorandum) to explore a wide range of reentry shapes and techniques. By taking the Gemini approach to a space program, Secretary McNamara estimated that $100 million would be saved in the following 18 months.

The Secretary of Defense explained his reasons for canceling the X-20. He stated that the purpose of the program had been to demonstrate maneuverable reentry and landing at a precise point. The Dyna-Soar vehicle was not intended to develop a capability for carrying on space logistics operations. Furthermore, the X-20 was not intended to place substantial payloads into space nor fulfill extended orbital missions. The Secretary of Defense stated that about $400 million had already been expended on a program which still required several hundred million dollars more to achieve a very narrow objective.[62]

A few days after the termination announcement Dr. Brown, in a memorandum to the Secretary of the Air Force, replied to the arguments of Dr. Flax and General Hester. Dr. Brown stated that before reaching a decision the Air Force alternatives were carefully considered. There were three objections. The Air Force recommended program involved construction of a space station and a new and larger X-20. The Department of Defense considered that such a large step was not justified and a test module and Gemini vehicle were chosen as the logical first step. Furthermore, the Air Force suggestion to cancel Gemini was not within the power of the Department of Defense since this was a NASA program. Lastly, the Air Force recommendation involved a greater degree of schedule risk than the chosen program. The Air Force proposal could not be accepted as a feasible substitute for the Manned Orbiting Laboratory program.[63]

Following Secretary McNamara's news conference on December 10, Air Force headquarters informed all of its commands of the termination of the X-20 and the initiation of an orbital laboratory program.[64] On the same day, General Schriever met with some of his staff to discuss the new space approach. He stated that both the orbiting laboratory and the expanded ASSET programs would be placed under the management of the Space Systems Division.[65] Later, General Schriever requested the Commander of the Research and Technology Division, Major General Marvin C. Demler, to aid the space division in the preparation of a new ASSET development plan. The objective of this program as first announced by Dr. Brown remained unchanged: the development of an advanced ferry vehicle.[66]

Although official instructions were not received from AFSC headquarters until December 17, the X-20 program office instructed the Dyna-Soar contractors and various Air Force agencies on December 10 to stop all activities involving the expenditure of X-20's funds.[67] On the next day Secretary Zuckert authorized the Air Force to terminate the X-20 program; however, it was to continue certain X-20 efforts which were deemed important to other space programs. A preliminary report was due no later than December 16.[68] The day following this direction the ASD program office recommended the continuation of ten activities: studies of pilot control of booster trajectories, fabrication of the Dyna-Soar heat protection system, construction of the full pressure suit, fabrication and testing of the high temperature elevon bearings, final development testing of the nose cap, flight testing on the ASSET vehicle of coated molybdenum panels, final acceptance testing of the test instrumentation subsystem ground station, development of the very high frequency (VHF) search and rescue receiver and transmitter, employment of existing Boeing simulator crew station and flight instruments for further research, and development of certain sensoring and transducing equipment for telemetry instrumentation.[69] On December 18 Air Force headquarters informed the program office that the Secretary of the Air Force had approved the ten items, and funding for continuation of these contracts would be limited to $200,000 a month.[70]

The X-20's engineering office, however, had recommended a list of several items for reinstatement which were in addition to the ten efforts continued by the program director. The X-20's Program Director had not supported the engineering office items either because he did not consider them of sufficiently wide applicability or he could not adequately establish their merit.[71] This list, however, was revised on December 14 by representatives from AFSC headquarters, the Space Systems Division, the Aeronautical Systems Division, and the Research and Technology Division. The officials decided to identify the items not only by technical area, as originally presented by the engineering office, but also by four categories. Category A involved efforts whose cost for completion would be equal to the termination expense. Category B comprised items which were applicable to various space programs. Category C included items which would contribute to the advancement of the state-of-the-art. The final classification, Category D, contained efforts which possessed a potential future use.[72]

On December 20, 1963 a revision of this list had been completed and coordinated with the laboratories of the Research and Technology Division. The items were classified both by technical area and the suggested categories. At the end of the month officials from USAF headquarters, AFSC headquarters, ASD, and RTD again reviewed proposed items for continuation and this time a new classification was suggested. Category I included items which would advance the state-of-the-art. Category II involved items which only required feasibility demonstration or design verification. Category III comprised equipment which was nearly completed, and Category IV were efforts which necessitated further justification.[73]

By January 3, 1964, a last revision of the proposed useful efforts had been completed. A Category V was added which included items that had been suggested for continuation by various organizations but were considered unacceptable by the X-20's engineering office. Essentially, the engineering office recommended for continuation the 38 efforts which comprised Categories I, II, and III. Included in these were the ten items which were being continued by the program office itself. A few days later General Estes requested from USAF headquarters authority to retain sufficient funds for program termination which would include $3.1 million for the completion of the first three categories.[74] On January 23 USAF headquarters informed AFSC that the Secretary of the Air Force had approved, with the exception of two items, all the efforts listed under the first three categories. The Air Force would allow an expenditure of $70 million from fiscal year 1964 funds for the Dyna-Soar program, $2.09 million of which would be directed towards completing the three categories.[75] The Research and Technology Division was then assigned authority to formulate a management plan for completion of this work.[76] The X-20's engineering office completed a plan at the end of January recommending that separate contracts be negotiated for the three categories of items which had not been already reinstated. These contracts would be administrated by the Research and Technology Division except for two which were to be transferred to the Air

Force Missile Development Center and the Air Force Flight Test Center.[77] While Air Force headquarters did not give an official approval, this plan was put into operation.

The Air Force calculated that Boeing had completed 41.74 percent of its tasks. The Minneapolis-Honeywell Regulator Company, the associate contractor for the primary guidance subsystem, had finished 58 percent, and the Radio Corporation of America, the associate contractor for the communication and tracking subsystem, had completed 59 percent of its work. At the time of Secretary McNamara's announcement, Boeing had 6,475 people involved in the X-20 program, while Minneapolis-Honeywell had 630 and RCA, 565. The governmental expenditure for these contracts amounted to \$410 million.[78]

While it had only approximately reached mid-point, the Dyna-Soar program definitely advanced the technology of radiation-cooled structures. Thirty-six X-20 tasks were continued and would directly contribute to other Air Force space efforts. Also significant was the initiation of an expanded ASSET program directed towards the development of a lifting, reentry shuttle vehicle. Paradoxically, the cancellation of X-20's development apparently made the maneuverable reentry concept far more acceptable to the Department of Defense and some elements of the Air Force than it had during the existence of the Dyna-Soar program.

NOTES

1. TWX, AFSDC-85081, Hq. USAF to Hq. AFSC, Dec. 11, 1961; SPD, DCS/Sys. & Log., Hq. USAF, Dec. 27, 1961.

2. Memo., R. S. McNamara, Secy. of Def. to E. M. Zuckert, SAF, Feb. 23, 1962, subj.: The Air Force Manned Military Space Program.

3. Memo., Secy. of Def. to Harold Brown, DDR&E, Jan. 18, 1963.

4. Memo., Brockway McMillan, ASAF/R&D to SAF, Mar. 15, 1963.

5. Memo., ASAF/R&D to SAF, Mar. 18, 1963.

6. Rpt., Dep/Tech., SSD, May 10, 1963, subj.: Response to Secretary McNamara's March 15, 1963 Questions, I, 2-19 to 2-23, 2-27 to 2-29, 2-37, 2-47c, 2-47h.

7. Ibid., 2-54c to 2-54j, 2-55 to 2-57, 2-63, 2-79, 2-87.

8. Ibid., ix-xiii.

9. Ltr., Maj. Gen. O. J. Ritland, Dep. to the Cmdr/Manned Space Flight, Hq. AFSC to Hq. USAF, May 22, 1963, subj.: Response to Secretary McNamara's March 15, 1963 Questions.

10. Memo., ASAF/R&D to Secy. of Def., June 5, 1963, subj.: Review of Air Force Space R&D Program.

11. Rpt., X-20 SPO, ASD, June 1, 1963, subj.: X-20 Anti-Satellite Mission, pp. 7, 8, 12, 21.

12. Ltr., Col. W. D. Brady, Acting Dep/Tech., SSD to Col. W. L. Moore, Prog. Dir., X-20 SPO, June 25, 1963, subj.: Program 706, Phase O Study.

13. Rpt., X-20 SPO, Nov. 18, 1963, subj.: Phase O Study of X-20 Program 706, I, 2, 14, 15.

14. Presn., W. E. Lamar, Dir., X-20 Engg. Ofc., RTD to SAF, July 8, 1963, subj.: X-20 Status Report.

15. Minutes, Col. C. R. Tosti, Exec. Secy., DSMG, Hq. USAF, July 23, 1963, subj.: Sixty-fifth Meeting, Designated Systems Management Group, July 12, 1963.

16. Memo., L. B. Johnson, Vice Pres. to R. S. McNamara, Secy. of Def., July 22, 1963, subj.: Space Stations.

17. Memo., McNamara to Johnson, Aug. 9, 1963, subj.: Orbital Space Station.

18. Memo., N. E. Golovin, Ofc., Science and Tech., Exec. Ofc. of the Pres. to A. C. Hall, Dep. DDR&E, Sept. 12, 1963, subj.: Briefing for Lees Subcommittee of PSAC Space Vehicle Panel.

19. Ltr., Maj. Gen. W. B. Keese, DCS/Plans, Hq. USAF to Hq. ASD, Sept. 19, 1963, subj.: Briefing to PSAC Panel on October 10, 1963.

20. Trip rpt., Lamar, Sept. 23, 1963, subj.: Briefing for President's Advisory Committee--Space Vehicle Panel.

21. Rpt. to PSAC, Hq. USAF, Oct. 10, 1963, subj.: Manned Orbiting Station and Alternatives, Vol. IV.

22. Interview, Lamar by C. J. Geiger, Hist. Div., ASD, Jan. 14, 1964.

23. Memo., A. H. Flax, ASAF/R&D, Hq. USAF, Sept. 18, 1963, subj.: Dyna-Soar Operational Capability Study; ltr., Lt. Gen. H. M. Estes, Vice Cmdr., AFSC to Hq. ASD, Oct. 25, 1963, subj.: Space Planning Studies.

24. TWX, SCLDS-27-11-3, Hq. AFSC to Hq. ASD, Nov. 29, 1963.

25. TWX, SCG-0-10-6, Hq. AFSC to Hq. ASD, Oct. 10, 1963.

26. Memo., Col. Moore, Oct. 30, 1963, subj.: Record Memorandum of the X-20 Presentation to Secretary of Defense McNamara, October 23, 1963, and Pertinent Background.

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CHAPTER VI

X-20: THE TECHNICAL LEGACY

Termination of the X-20 effort did not immediately result in a shutdown of all X-20-related work. Testing of various X-20 components and design features continued well into the middle 1960's, using both ground test facilities and such flight research vehicles as the ASSET. The X-20 had a profound impact upon the state of technical knowledge regarding hypersonic flight, and over the spring and early summer of 1964, the Boeing Company assembled a comprehensive "lessons learned" document, Report D2-23418, highlighting the technical advances that had been made in support of the X-20's development effort. This document stands as the clearest technical analysis of the program and what was achieved--as well as what remained to be done--that is available. It has been edited and excerpted here as the final chapter of the X-20 case study:[1]

The purpose of the X-20 program was to develop and demonstrate a piloted research vehicle capable of orbital flight, controlled maneuverable entry from orbit, extensive exploration of the hypersonic flight regime, and horizontal landing at a designated location. Because of its broad scope, the program represented the deepest penetration into lifting entry technology that has been made. The advances made by the X-20 effort range from the development of theoretical concepts to the implementation of flight hardware.

More than 16 million man-hours were devoted to the X-20 program of which 11 million were spent on engineering. Over 14 thousand hours of wind tunnel tests and nearly 9 thousand hours of simulator time were required to achieve the final design. In addition to the advanced technical requirements of the X-20, a substantial number of man-hours were devoted to systems engineering, glider-booster integration, associate contractor coordination, and subcontractor management.

This document presents a cross section of the technical advances of the X-20 program. Particular emphasis has been placed on aerodynamics, structures and materials, and subsystems. The technical advances made during the X-20's development are applicable to both current and future programs.

Mission Profile

A typical one-orbit flight profile for the X-20 glider is shown in Figure 1. The orbital vehicle was to be boosted eastward from Cape Kennedy to a velocity of 24,470 feet per second and an altitude of 320,000 feet at boost burnout. The vehicle then coasted to apogee at 480,000 feet. Separation from transition and transtage was to occur at initiation of entry. The glider would then proceed to a landing 107 minutes later at Edwards Air Force Base. Critical entry heating would have occurred over the Pacific Ocean at velocities between 17,000 and 24,000 feet per second.

Aerodynamics and Flight Performance

This section contains technical information developed during design of the X-20 glider in the areas of aerodynamics, flight mechanics, flight controls, and aerothermodynamics. This technical information ranges from detail configuration effects on stability and local heating to recommended techniques for hypersonic flight. Over 14,000 wind tunnel test hours, which included 1800 hours subsonic, 3700 hours supersonic, and 8500 hours hypersonic,

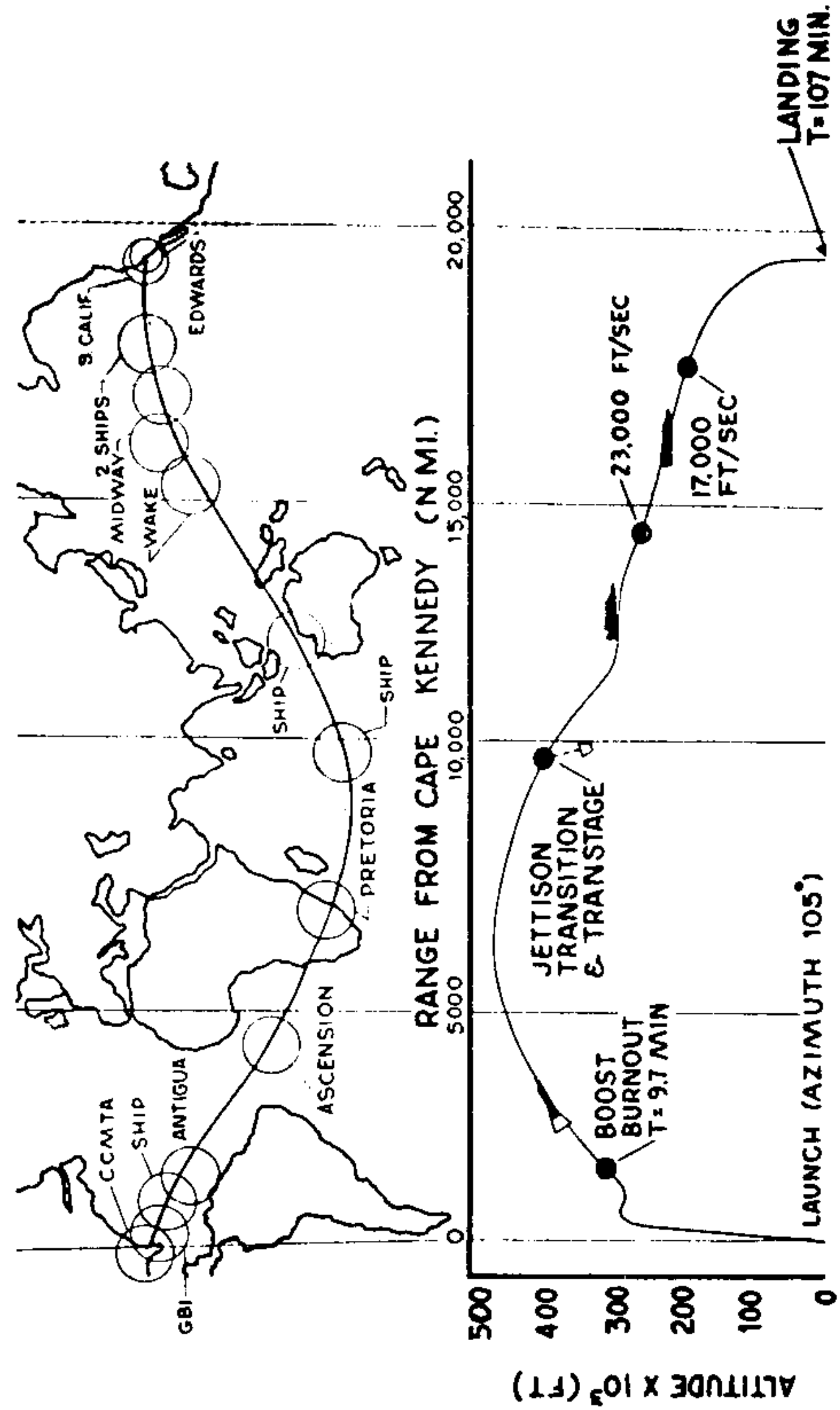

Figure 1

X-20 One-Orbit Mission

together with almost 9000 hours of simulator time, were required to arrive at the final design of the X-20.

X-20 Configuration

The specific design, flight, and operating constraints for the X-20 glider were complex and required unique design solutions. The most demanding of these requirements included atmosphere entry at orbital speed, flight to designated location with horizontal landing, attainment of 1500 nautical mile lateral range capability, attainment of hypersonic L/D ratio of 1.5 or more, attainment of hypersonic lift coefficient of 0.6 or more, maintenance of positive static stability throughout flight, and capability of manned abort throughout the mission. The flight regime operating limits were a dynamic pressure range of 0 to 900 psf (the latter in case of an abort during boost), a velocity range of Mach 0.3 to 30, and an angle-of-attack range of 18 to 55 degrees during hypersonic flight. Further design requirements included a radiation-cooled structure capable of surviving the entry thermal environment for 4 missions, a payload capacity of 75 cubic feet and 1000 pounds, attainment of 91.3 percent glider flight reliability and 96 percent pilot safety, and a maximum glider and transition section gross weight of 18,000 pounds.

Extensive trade studies and configuration tailoring were accomplished to meet the required design and flight characteristics. Following are some of the design compromises made after these trade studies were completed.

1. Wing sweep and leading-edge radius were a compromise between the hypersonic and subsonic L/D ratio and the stagnation-line heating limit imposed by the thermal qualities of available refractory materials.

2. The fins were located outboard to provide stability and yaw control at high angles of attack during hypersonic flight.

3. The fins were toed in 10 degrees to take advantage of increased hypersonic lift curve slope and reduce required fin area. The toe-in angle was a compromise with increased weight from higher fin loads during boost and increased drag during flight.

4. The fin sweep and leading-edge radius were a compromise among effects on interference heating, subsonic lift curve slope, transonic shock stall characteristics, and supersonic rudder hinge moments.

These design analyses and analytical techniques developed during the X-20 program are applicable to other lifting entry vehicle programs.

X-20 Static Stability

During X-20's development, a design goal was established to achieve a statically stable glider within the normal range of entry and glide conditions. This was done to ease the task of the flight control system; to provide satisfactory augmented handling qualities; and to provide satisfactory unaugmented handling qualities to the extent possible.

Static longitudinal stability is presented in Figure 2 as trimmed aerodynamic center for various angles of attack through the speed range of the glider. An instability existed for a small range of high subsonic Mach numbers at high angles of attack. An instability also existed at supersonic speeds at intermediate angles of attack, although this instability was small (approximately 1 percent m.a.c.) and disappeared at higher angles of attack. Also, as shown on the figure, static directional

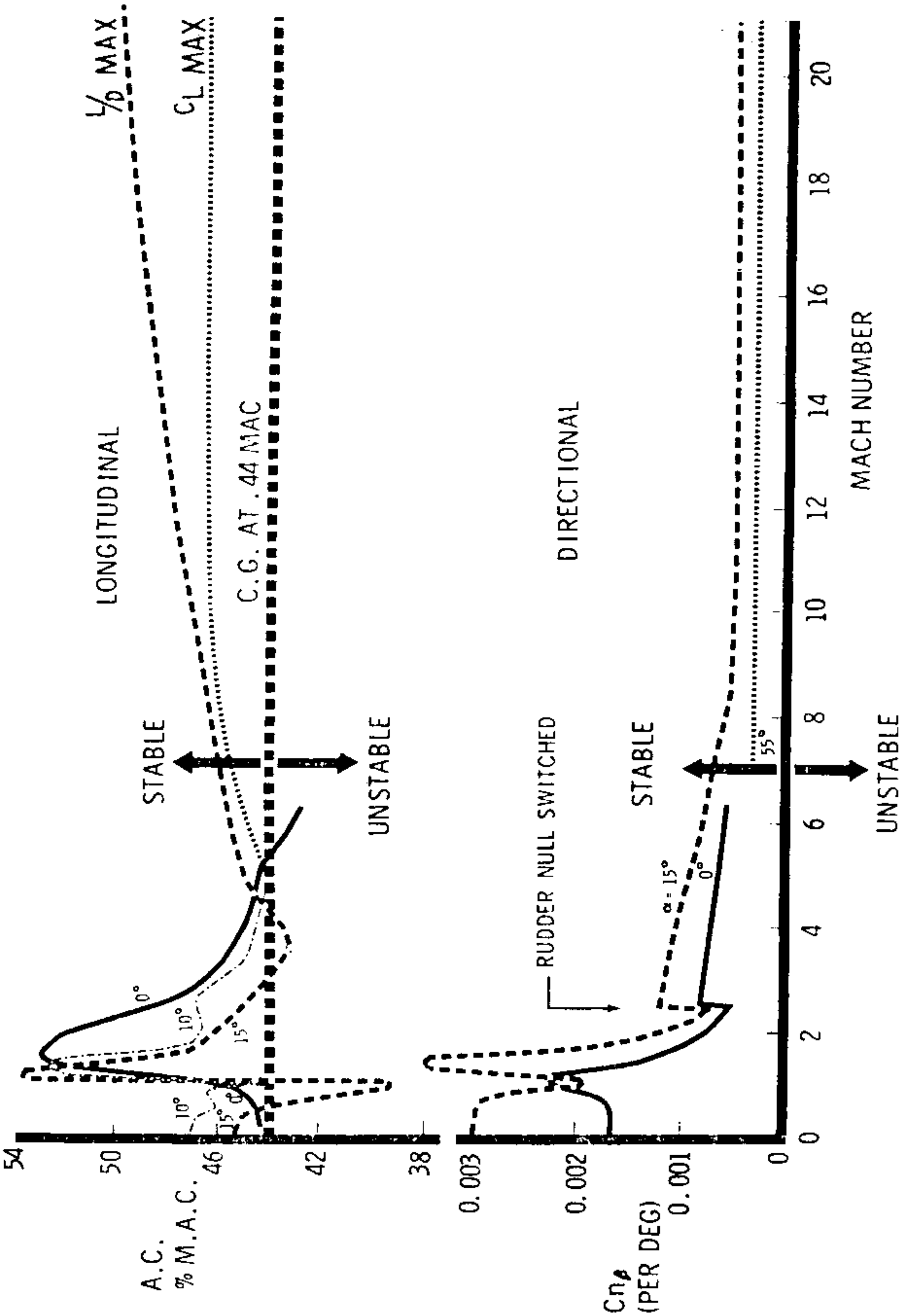

Figure 2

Static Stability

stability existed through the complete range of required flight conditions.

In summary, the glider provides satisfactory handling qualities (Cooper ratings from 1 to 3) under the normal range of entry and glide conditions with stability augmentation. In addition, the aerodynamic stability configuration made emergency control (Cooper ratings less than 6.5) possible at all Mach numbers with either pitch axis or the lateral-directional axes unaugmented. Also, emergency control was possible for many flight conditions with complete loss of augmentation.

Aerodynamic Interaction Effects

The interaction of aerodynamic effects may complicate configuration design, requiring tailoring and refinements not usually considered in preliminary analyses. Following are two examples of configuration tailoring to overcome aerodynamic interaction effects.

The basic wing section on the April 1960 X-20 configuration, a double wedge upper surface and flat lower surface with rounded leading edges, was chosen for good hypersonic characteristics and easier manufacturing. This design would have required foldout fins for good low-speed stability. To eliminate foldout fins, the upper surface was tailored to maintain good hypersonic characteristics and improve low-speed stability. Modification of the upper wing surface, however, resulted in directional instability at small angles of side-slip at transonic speeds and an increase of 30,000 inch-pounds in elevon hinge moment at low supersonic speeds.

A wind tunnel program at subsonic through supersonic speeds to evaluate modifications required to correct these deficiencies resulted in the addition of the aft body ramp shown in Figure 3.

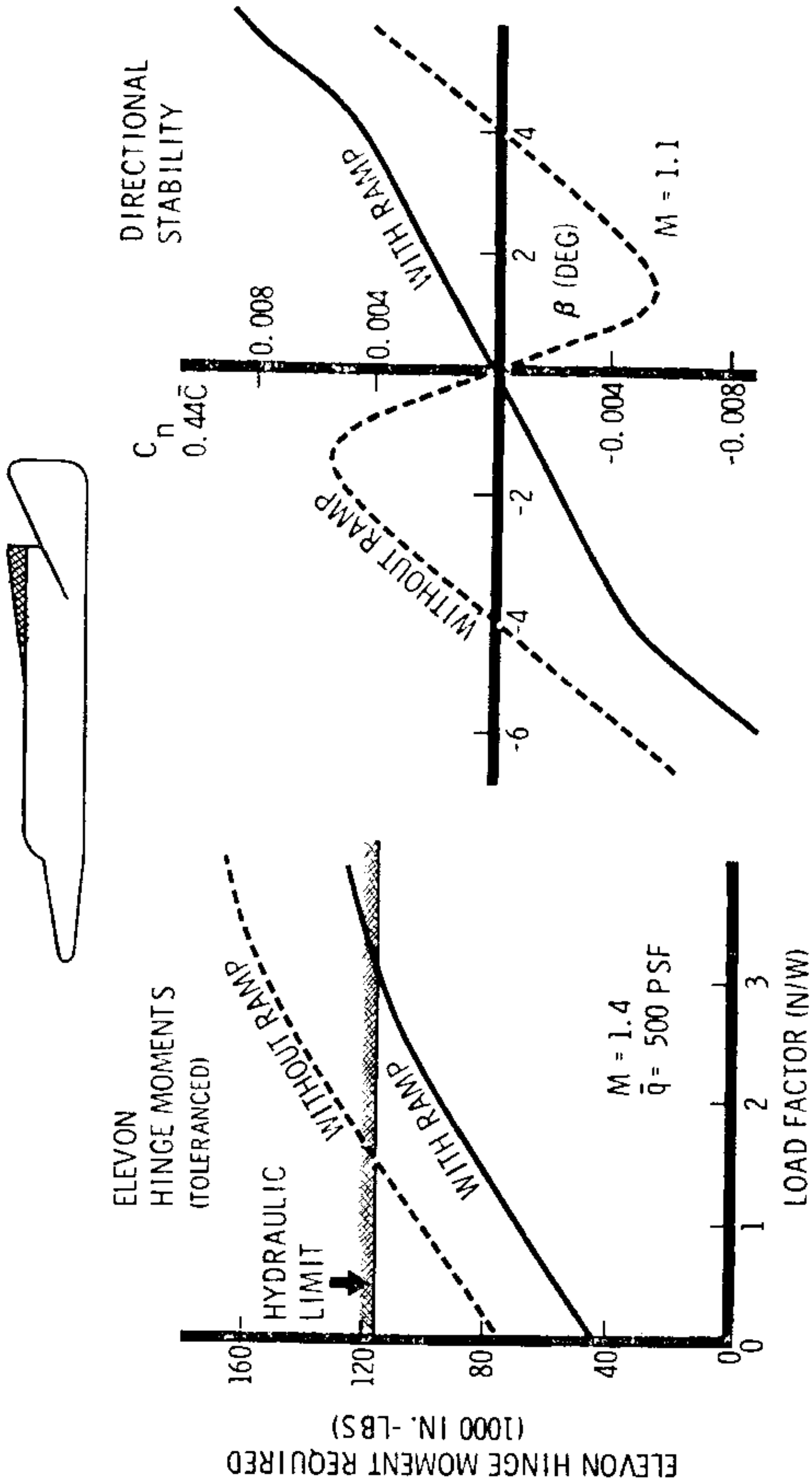

Figure 3

Effect of Aft Body Ramp

The ramp caused a noseup pitching moment which reduced the elevon angle required for trim, thereby reducing the hinge moments as shown. The static directional instability was eliminated by the influence of the ramp on the upper wing separation vortex. A favorable pressure field was formed so that the adverse interference effect of the vortex on the vertical tails was reduced and stability was restored.

Another example of an aerodynamic interaction was the gap between the vertical fin and the elevon. The aeroelastic and thermoelastic analyses showed a requirement for a large clearance at the outer end of the elevon. The resulting gap was found to cause low-speed, low-attitude pitchup if it was too large. Tailoring provided proper clearance without sacrificing low-speed stability.

These two examples demonstrate the iterative process involving analysis and test which are required to achieve a satisfactory configuration.

X-20 Hypersonic Aerodynamics

Before the X-20 program, hypersonic aerodynamic data had been derived primarily from ballistic missile programs using blunt, nonlifting entry bodies. The X-20 glider was the first slender, lifting, entry vehicle designed for intensive exploration of the hypersonic flight regime.

AXIAL FORCE CORRELATION

X-20 aerodynamic wind tunnel test data of axial force coefficients at hypersonic speeds were not easily compared with analytical predictions because there was considerable scatter in the test data and because it was difficult to predict skin friction which is a large contributor to the total axial forces. An analytical method for predicting skin friction was developed which utilized heat transfer data from theory and wind tunnel test. An extensive data correlation study of several wind tunnel tests showed that, for a given a, axial force coefficient varied approximately linearly with a correlation parameter relating Mach number and Reynolds number in the form $M/\sqrt{Re_{\bar{c}}}$ as shown in Figure 4.

The analytical method was used to extend aerodynamic data to Mach numbers and Reynolds numbers other than those tested. Since wind tunnel test conditions do not match flight temperatures and velocities, the analytical method was also used to correct wind tunnel data to full-scale flight conditions.

PREDICTION OF HYPERSONIC LIFT

Hypersonic lift coefficients for the X-20 glider were predicted by combining analytically determined normal force and axial force coefficients. Normal force is dependent primarily on surface pressures and was found by integrating local surface pressures over the various components of the glider. Several methods were used to derive local pressure coefficients which depended on Mach number and surface inclination. These include modified Newtonian theory, hypersonic small disturbance theory, Prandtl-Meyer expansion, and tangent-cone theory. Skin friction was estimated as described above.

Figure 4 shows a typical analytical estimate of lift at Mach 22 as a function of angle of attack. Wind tunnel data points obtained in the Boeing Hotshot Tunnel show consistent agreement with this analytical prediction.

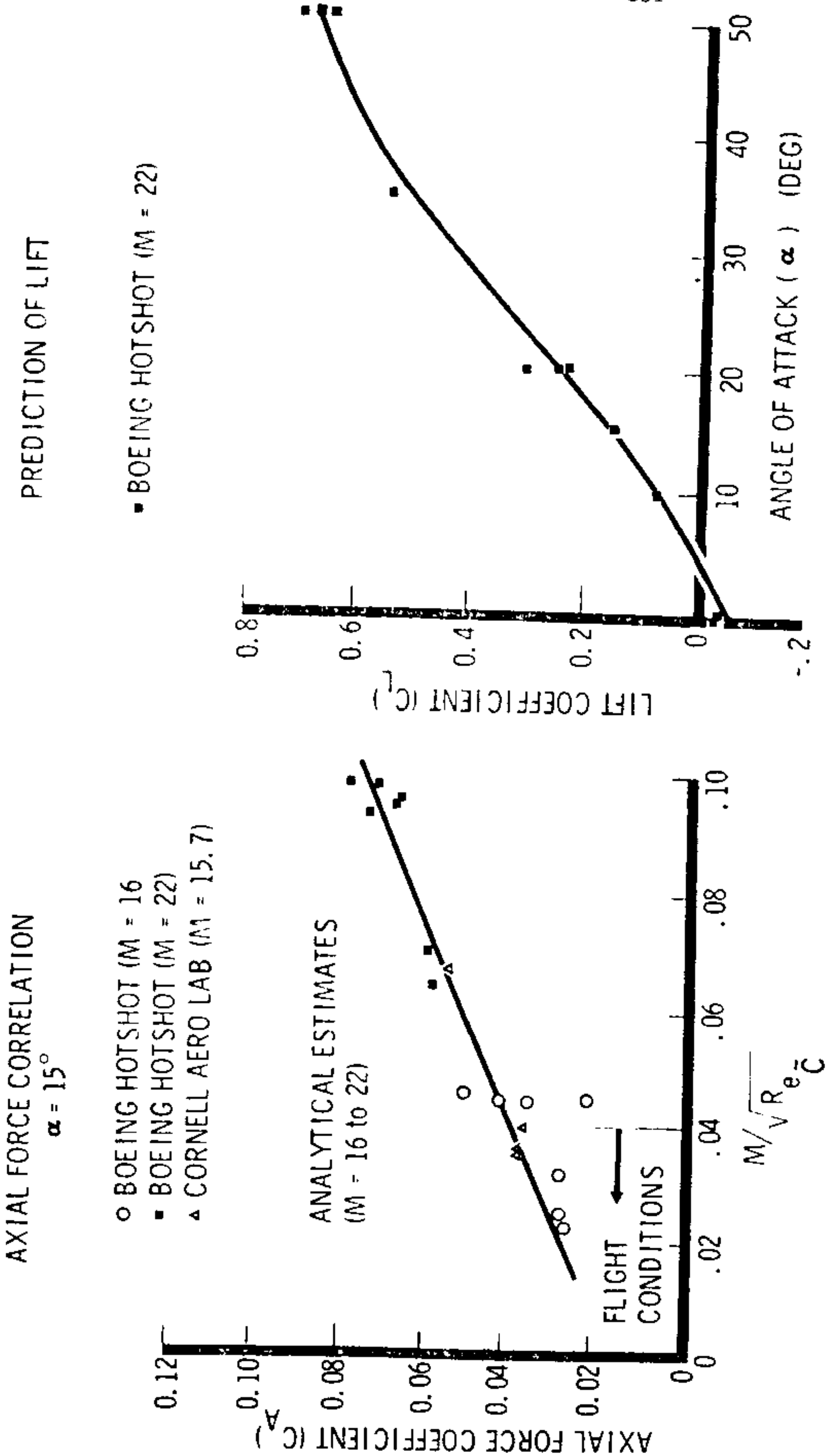
AXIAL FORCE CORRELATION
α = 15°
○ BOEING HOTSHOT (M = 16
■ BOEING HOTSHOT (M = 22)
▵ CORNELL AERO LAB (M = 15.7)
ANALYTICAL ESTIMATES
(M = 16 to 22)
FLIGHT CONDITIONS
AXIAL FORCE COEFFICIENT (C_A)
0.12
0.10
0.08
0.06
0.04
0.02
0
0
.02
.04
.06
.08
.10
M/√Re_C̄
PREDICTION OF LIFT
■ BOEING HOTSHOT (M = 22)
LIFT COEFFICIENT (C_L)
0.8
0.6
0.4
0.2
0
-.2
10
20
30
40
50
ANGLE OF ATTACK (α) (DEG)

Figure 4

Laminar Theory and Data Improvement

The X-20 studies indicated that laminar heating rate theories based on exact, real-gas boundary layer solutions are accurate for simple shapes. Experimental support for this conclusion is given in the left figure in Figure 5. The curves shown on this figure are the actual wind tunnel test data that have been normalized. A value of 1.0 indicates exact agreement of theory and experiment. The nonlinear abscissa is graduated so that the normal distribution of random errors plots as a straight line, the slope of the line indicating the scatter of the data. In this figure, lines have been faired through actual data. The scatter in the laminar stagnation point data has been reduced by a factor of 3.5. The corresponding change in mean value (indicated by the value of the faired lines at the 50th percentile) has shifted only a few percent, indicating that scatter in the data are due to random experimental errors, rather than systematic variations. Since the stagnation point flow equations are basically identical to all laminar flow equations, this curve tends to confirm all laminar heating rate theory.

The reduction in scatter supporting the above conclusions is partially due to an improved method of data reduction developed by Boeing. Much of the scatter in conventional wind tunnel data is due to heat conduction effects; one type due to initial transients and the second due to aerodynamic heating. The effects of aerodynamic heating can be shown to increase consistently with time. As shown by the right hand figure in Figure 5, the consistent effect of aerodynamic heating is apparent in the data after the initial transients have disappeared. Extrapolation of this trend back to the initial model temperature yields the true heat transfer rate, unaffected by conduction errors. The application of this method has reduced the scatter in laminar stagnation point data taken in Arnold Center Tunnel B from 16 percent to less than 5 percent.

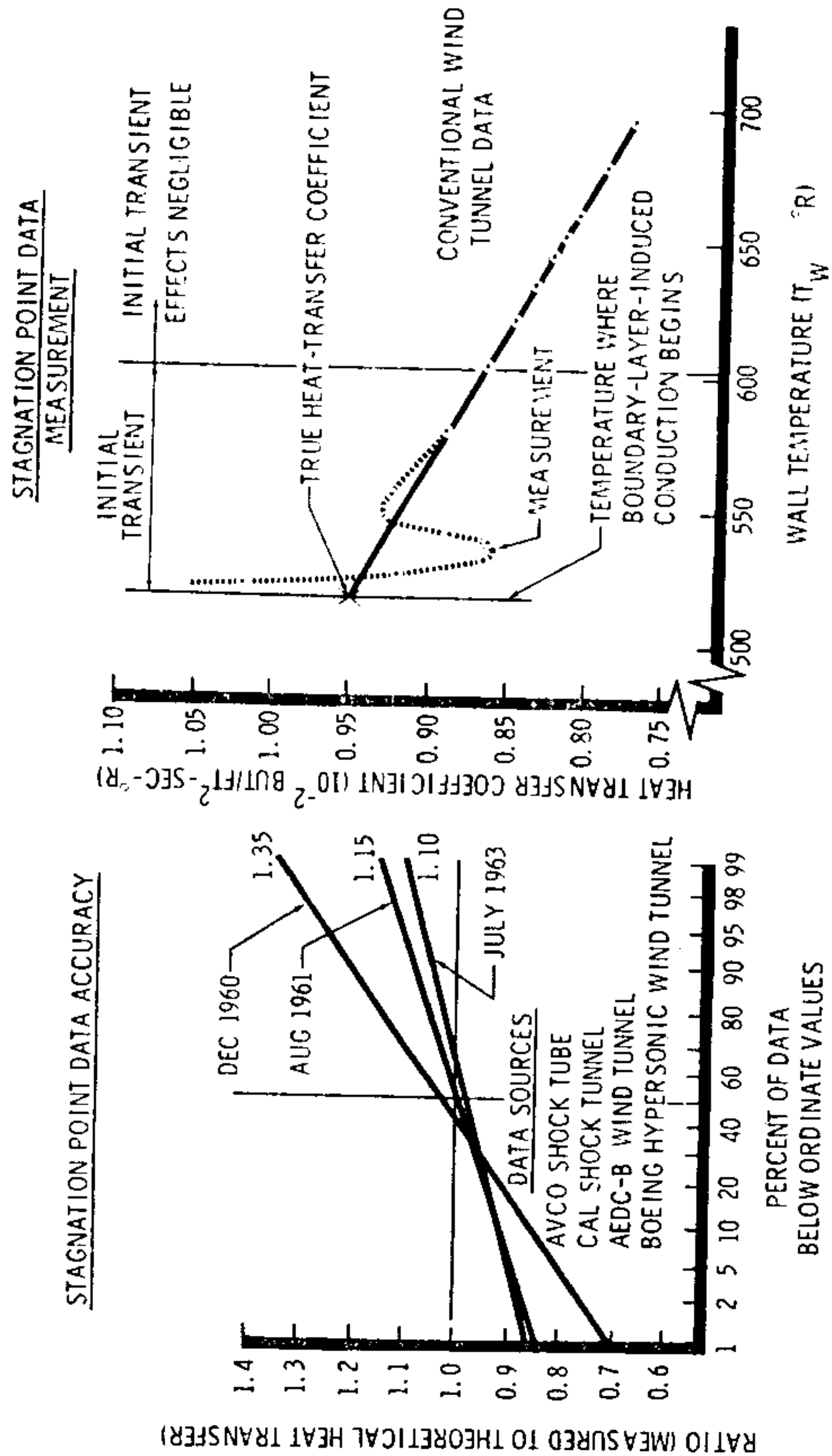

Figure 5

Laminar Theory and Data Improvement

Turbulent Heat Transfer

True simulation of the hypersonic entry environment cannot be accomplished in conventional ground test facilities. The complex flow associated with maneuverable lifting entry vehicles requires extensive theoretical knowledge. Since there has never been a rigorous turbulent theory, a major effort was made to improve turbulent flow analysis. Early in the X-20 program, turbulent heating rate analyses were based on an essentially empirical ideal-gas reference temperature method. This approach was substantiated by wind tunnel data available at that time and by limited shock tube data with dissociation levels as high as 30 percent.

Later, a new turbulent heating rate method was devised by R. A. Hanks of The Boeing Company, using exact laminar boundary layer theory as a starting point. The new method, when compared to other methods, predicted nearly the same heating rates for conditions ordinarily available in ground facilities, but significant differences were predicted for actual flight conditions. These predictions were confirmed by the data taken in the X-15 program, as shown in the graph on the left of Figure 6. On the basis of the X-15 data, the conclusion might be drawn that the other methods are, in general, conservative. This conclusion is, however, not supported by the new method, as illustrated in the right-hand graph. Here, the new method is compared with the earlier empirical ideal-gas reference temperature method. At the higher X-20 velocities the results of the empirical method are lower with respect to those of the new method, rather than higher as in the X-15 regime. Significantly, the velocity range in which the two methods are in near agreement is typical of the shock tube data which provided the major justification of the empirical method. These examples illustrate the caution with which empirical methods must be used, as well as the consequences of incomplete simulation.

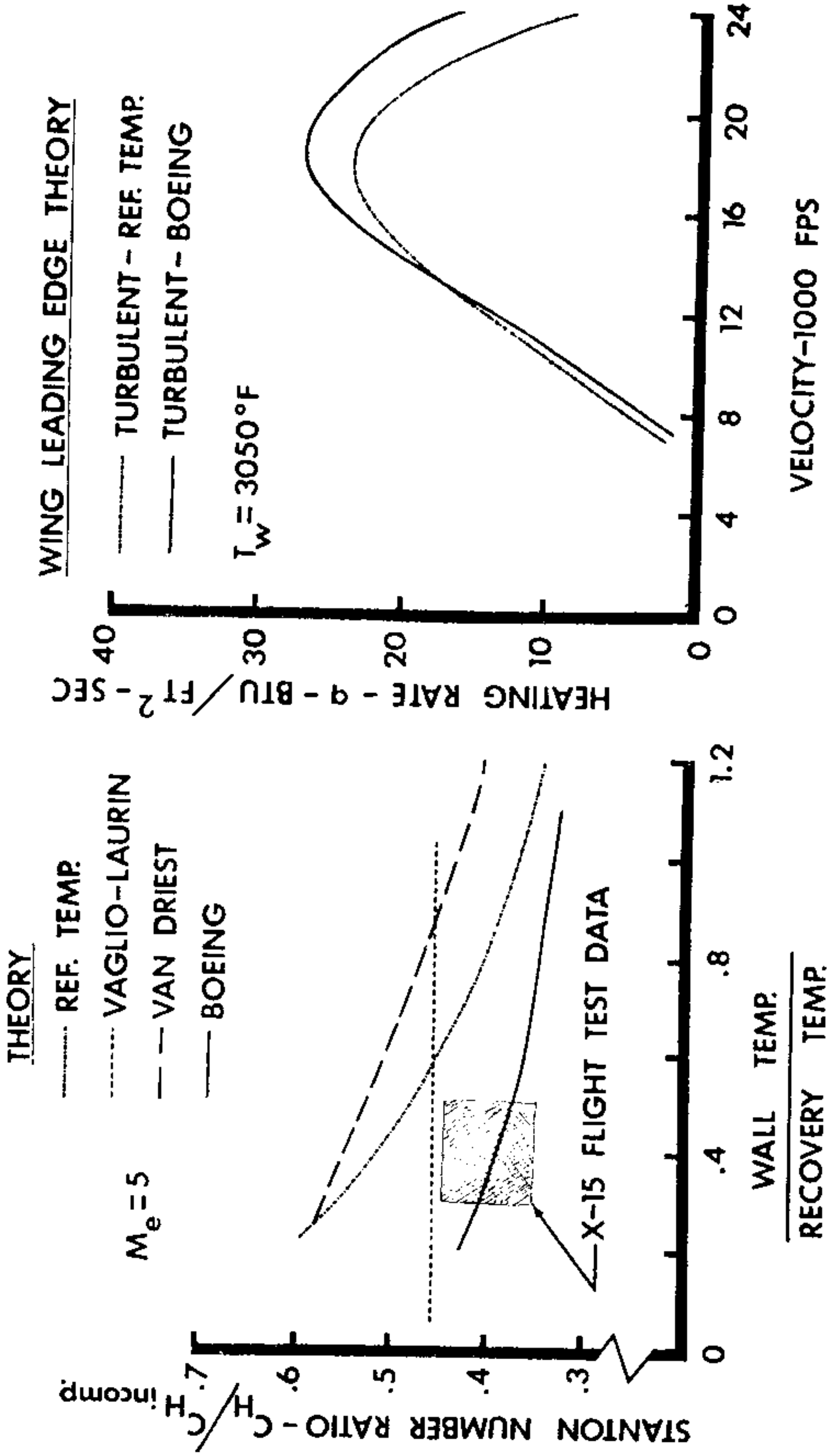

Figure 6

Turbulent Heat Transfer

Design Detail Heating

The successful design of a maneuverable lifting entry vehicle requires careful attention to detail heating. Excessive heat at almost any location could result in loss of the entire vehicle, especially since local partial failure (such as panel crack) might lead to further heating rate increases. Figure 7 shows examples where this attention paid off.*

1. Manufacturing tolerances and fabrication techniques cause some roughness: thermal expansion requirements at high temperatures also cause surface roughness in the form of laps, joints, and waves. Small surface waves, which were planned at one time for use on the X-20 to control thermal buckling, were found to cause large local heating rate increases, even when very shallow and highly swept. As shown, increases of 50 percent occurred on a typical test model.

2. Inward leakage has adverse effects on both external heating rates and internal temperatures. Typical resulting increases in heating are illustrated in Figure B. Leakage must be controlled or eliminated in areas of relatively high local pressures and heating rates. Such areas of the X-20 include expansion joints between leading edge and lower surface panels, control surface hinge lines, and landing gear doors; leakage control was affected by continuous insulation beneath panels, control of gap dimensions, or physical seals as required.

3. The X-20 fin was placed entirely above the wing with the leading edges highly swept to eliminate interference heating. Fin heating rates did not seriously restrict performance of the X-20. There was still a pronounced interference heating effect. Vertical

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*Available data from the Space Shuttle's own flight testing phase indicates that the X-20 would have had no thermal problems during even a high crossrange reentry; naturally, Boeing cannot be faulted for having taken a cautious and (in retrospect) overly conservative approach given the limited data available on structures and reentry heating in the early 1960s.

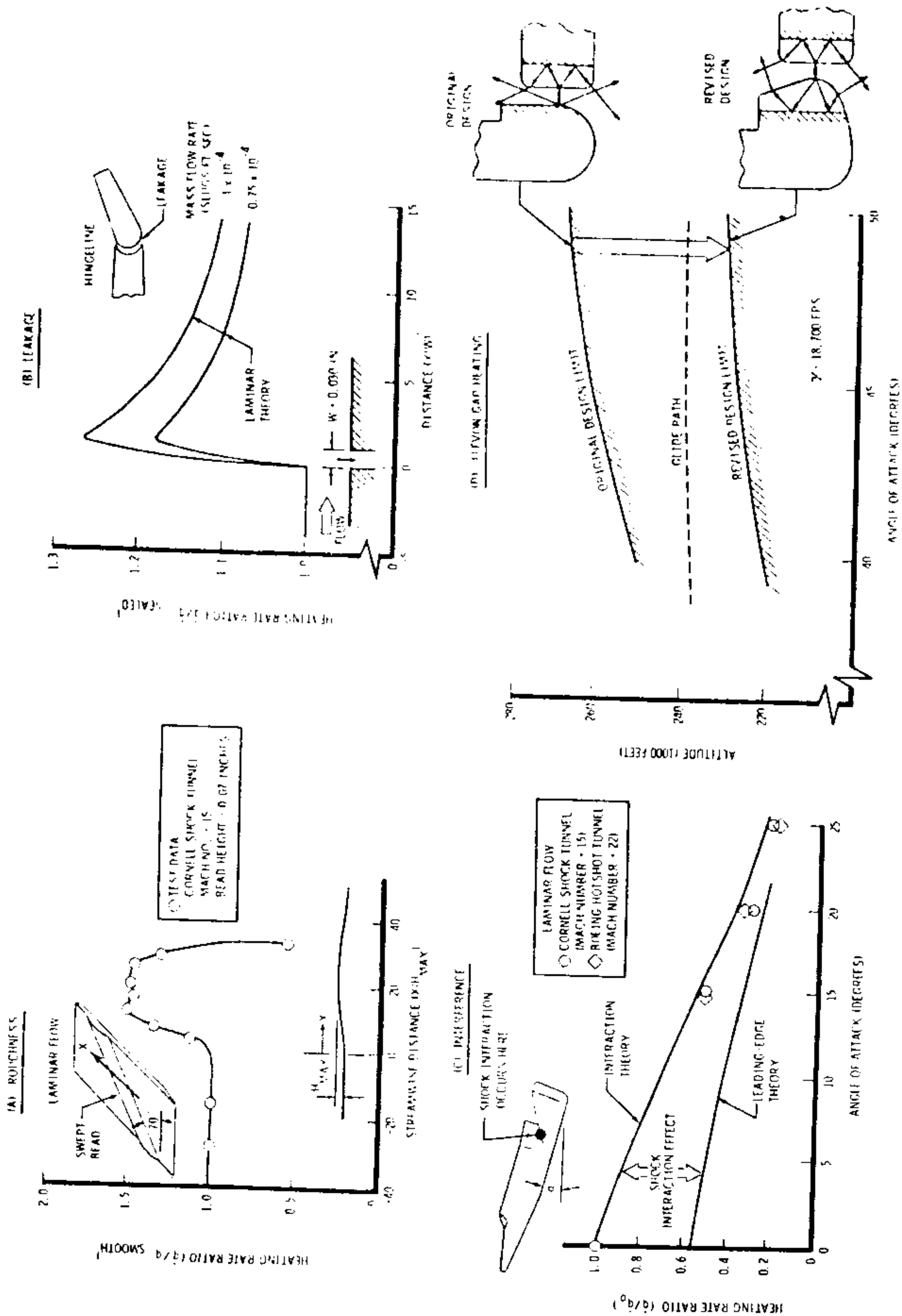

Figure 7

Detail Design Heating

fin laminar heating rates are much greater at low angles of attack than predicted by theory, due to the shock wave generated by the wing interacting with the flow field surrounding the fin. For this case, it was possible to develop a theoretical laminar method to predict the increases.

4. On the X-20, the region between the fin and elevon became a critical heating problem, not because of high heating rates but because of a very low "view factor" available for radiation of the convected heat. As shown in the figure, the initial design of the fin-elevon region was such as to cause the gap region to be critical above the glide line of the X-20. This condition was corrected by redesigning the fin and the elevon to provide internal radiation relief.

Hypersonic Maneuver Capability

Figure 8 illustrates maneuver limits, maneuver capabilities, and piloting techniques developed for the X-20 glider. Wing-level equilibrium glide altitudes are shown in relation to the minimum flight altitude as restricted by glider temperature limits. The insert shows elevon deflections required in relation to elevon deflection limits for a typical attitude maneuver. Both temperature limits vary with angle of attack.

It should be noted that the basic glider limits (altitude vs. angle of attack) are displayed on the energy-management display indicator which shows the pilot the proximity of the glider to the temperature limit. Not all limits like elevon and rudder deflection limits can be displayed. Therefore, maneuver requirements, capabilities, and limits must be carefully evaluated. The display is a useful aid, along with rate of climb indicator, in damping altitude oscillations, maneuvering, and establishing equilibrium glide.

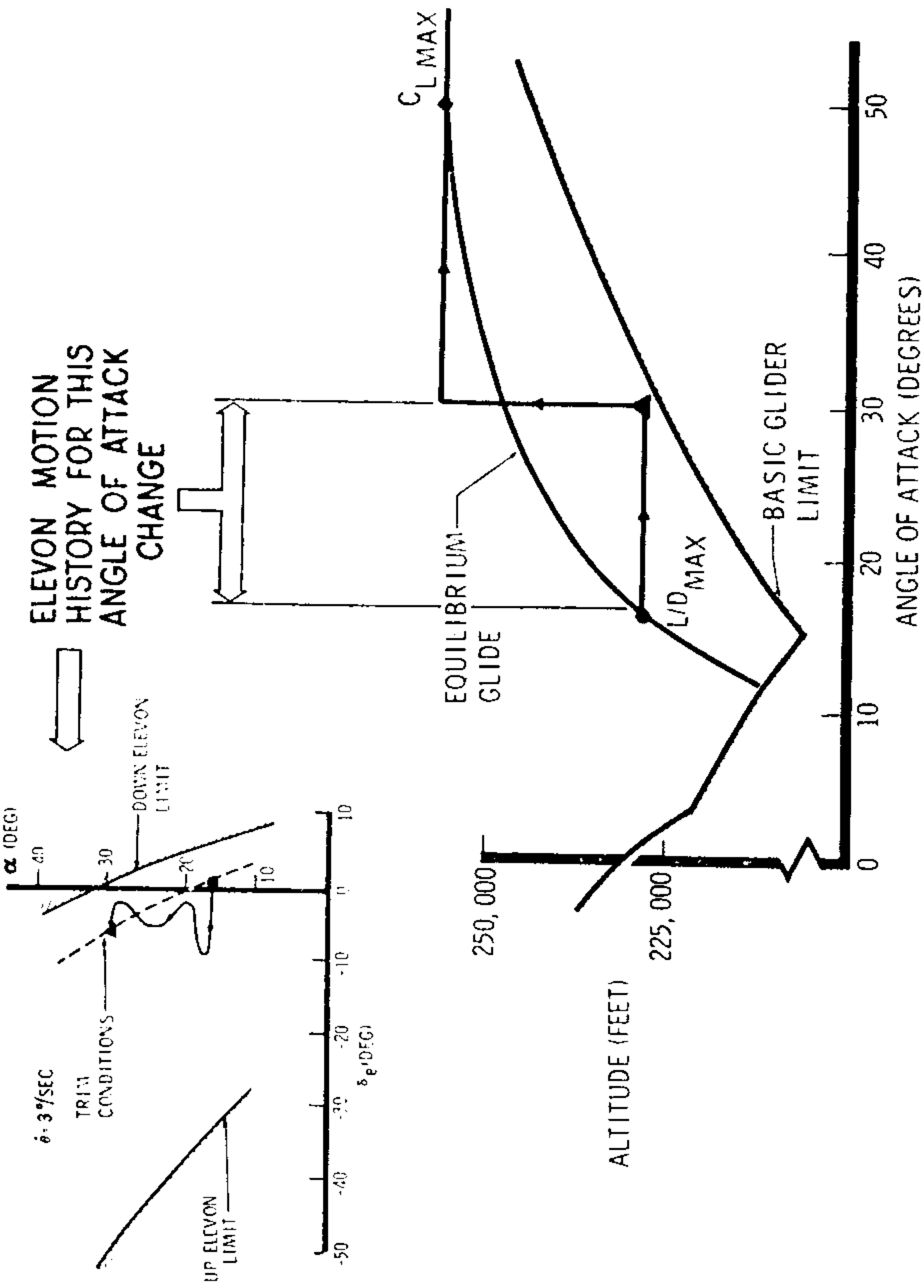

Figure 8

Hypersonic Maneuver Capability

At a particular glide condition, like L/D maximum in the figure, attitude maneuver capability is limited by heating. The pilot cannot maneuver directly to the angle of attack for $C_{L_{max}}$ for example, but must go to an intermediate angle of attack and wait for the altitude to change before completing the maneuver as shown. The maneuver can be accomplished with minimum overshoot or oscillation by selecting an intermediate angle of attack that corresponds to approximately 50 percent of the desired altitude change.

Also, surface deflection limits must be considered in maneuvers at any given altitude. In the example shown by the inset, the pilot was asked to pitch at approximately three degrees per second from the L/D_{max} condition to the angle-of-attack limit. The resulting elevon deflection shows that limits were not exceeded. For any normal maneuvering no problems were encountered, hence no surface limiting was employed. This X-20 experience indicates that, should elevon heating have become critical, a simple pitch rate limiter should be adequate for protecting the elevon from thermal damage.

Energy Management Display Indicator

The Energy Management Display Indicator (EMDI) is a special display developed on the X-20 program to enable the pilot to stay within structural thermal limits of the vehicle, reach the desired landing site, and attain the desired test conditions. Since these are concurrent tasks, two sets of information appear on a single display. The display is a 4-inch cathode ray tube with a set of transparent overlays which advance automatically during flight as a function of velocity. The EMDI has been evaluated in the flight simulator by the X-20 consultant pilot group. It is shown in Figure 9.

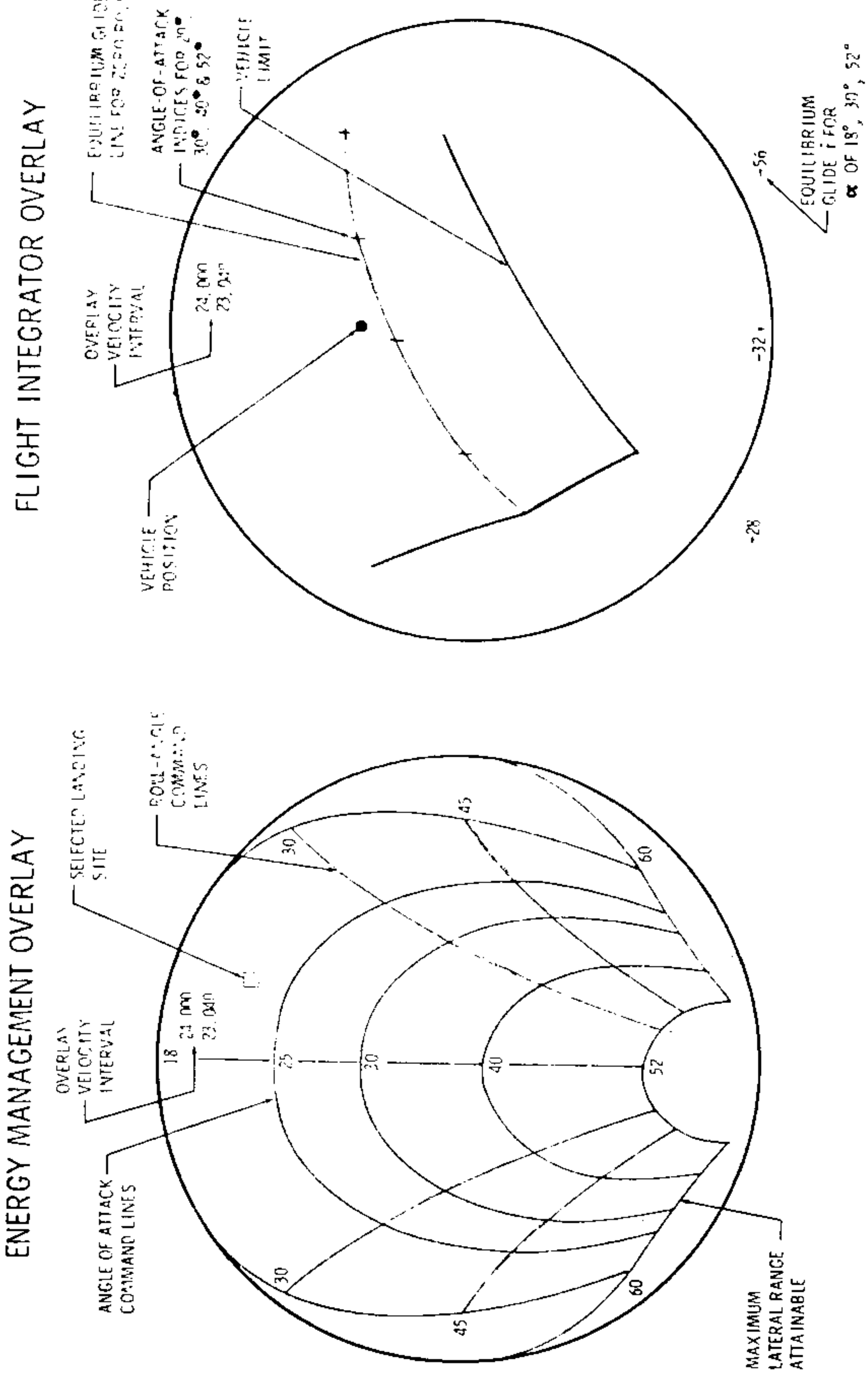

Figure 9

Energy Management Display Indicator

The Flight Integrator Display shows vehicle proximity to structural limits and establishes equilibrium glide and test conditions. Lateral motion of the spot reflects changes in glider angle of attack and vertical motion reflects changes in density altitude which are computed in the glider guidance computer. To obtain density altitude, the inertial altitude is corrected by using aerodynamic acceleration measurements within the computer altitude stabilization loop.

The Energy Management Display directs the pilot to a landing site and shows the glider's capability for test maneuvers enroute. This display avoids the requirement for large onboard computer by graphically displaying range capability on precomputed footprint overlays. The selected landing site is driven laterally and vertically as a function of crossrange and downrange. The overlay footprints show required angles of attack and roll that, if held constant, will just get the glider to the landing site. The pilot would normally overfly the command in order to center the landing site within his range capability.

Adaptive Gain Computer Performance

The X-20 was designed to operate within a broad flight envelope. The flight control system had to perform inside and outside the sensible atmosphere and with two aerodynamically different configurations (glider and abort).

Four control modes, three manual, and one automatic were provided. Normal operation was manual with the loop gain adjusted by the adaptive gain computer. At pilot option, the gain could be switched to one of three preselected fixed values. A manual direct mode, with control actuation bypassing the stability augmentation system, was provided for ultimate emergency.

Reliability was provided through major component rather than axis redundancy. Mean time between failures of the type that could cause switchover from the augmented mode to a manual direct mode is estimated to exceed 50,000 hours for the system.

Uniform handling qualities were provided by "shaping" the pilot's commands with a model and forcing the vehicle to follow the model output through the use of a high forward-loop gain. The gain computer was designed to sense the control surface limit cycle which occurred at critical gain, and to reduce the gain when the amplitude of this oscillation exceeded some small prescribed value. Pilot inputs and atmospheric turbulence both had frequency components within the spectrum of the gain changer filter and degraded the performance as shown. Both the pilot input and the atmospheric turbulence spectrum had their strongest frequency components at a frequency slightly lower than the limit cycle frequency. Thus it was possible to introduce an "up logic" circuit which had a lower authority and frequency bandwidth. This filter output was mechanized to drive the loop gain up. Gain holding qualities and the control response was vastly improved in the presence of pilot inputs and atmosphere turbulence.

Piloted Boost Simulation

Boeing was given a supplemental contract to the X-20 program to study pilot control during boost.

The study was completed in December 1962. The Titan III/X-20 air vehicle was used in a 6-degree-of-freedom fixed-base simulation. Approximately 100 flights were made using X-20 consultant Air Force pilots. A fixed-base simulation was used because results from a dynamic simulation of the X-20 boost problem on the Johnsville Centrifuge showed no significant effect on pilot performance because of the combined acceleration, pressure suit, and boost vibration environment.

The results of the fixed-base study showed that the pilot could successfully fly the boost trajectory, stay within limit constraints as defined by load, staging and malfunction detection system limits, and achieve system performance objectives. Stability augmentation was required.

Structures and Materials

The X-20 program provided sufficient research and development in structures, materials, and manufacturing processes to allow design and fabrication of a manned glide entry system. Significant advancements were made in:

- Superalloy components:
- Refractory alloy components:
- Ceramic alloy components:
- High-temperature bearings:
- High-temperature thermal insulations:
- Test techniques and miscellaneous developments.

Structural Component Advancement

The X-20 thermal environment demanded a structure capable of operating at temperatures well beyond the capability of production materials available in 1958. A pinned and fixed-joint truss was selected as the primary structure. This concept minimized the effect of thermal expansion stresses, and is shown in Figure 10.

Conventional structural materials such as aluminum, titanium, and stainless steel which could operate at temperatures up to 600°F have been replaced by a nickel superalloy, Rene' 41, originally developed for jet engines. This alloy has allowed extension of the maximum temperature tolerance of primary structural components to

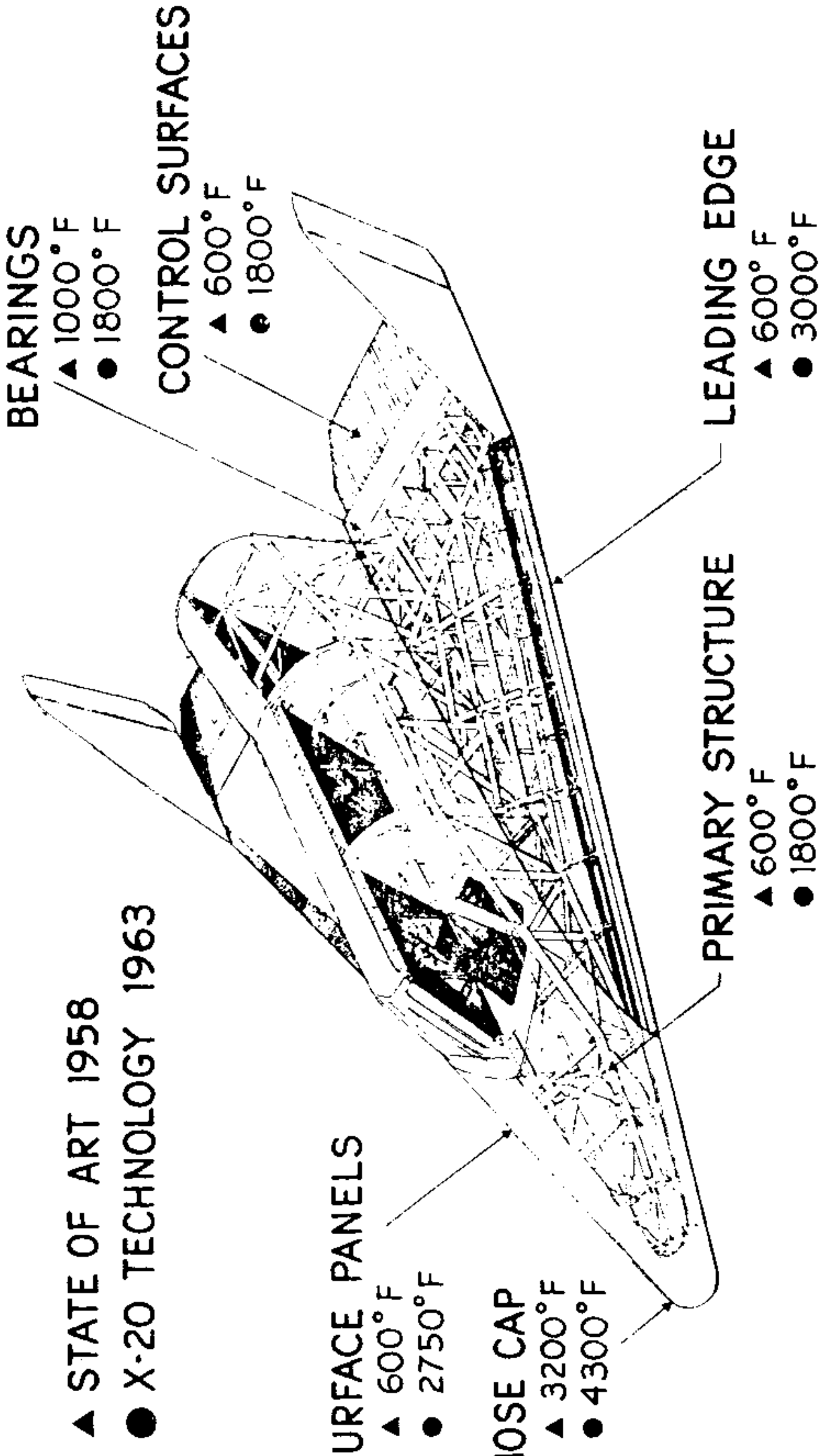

Figure 10

Structural Component Advancement

1800°F. Surface skin panels have been developed to accommodate a temperature of 2750°F. A D-36 columbium alloy heat shield with a Boeing-developed, oxidation-resistant coating and a silica-fiber insulation was developed to thermally protect the primary load-carrying Rene' 41 substructure. An extensive materials, design, fabrication, and development test program led to two structurally different zirconia nose cap components, each of which were successfully ground tested to the design environment. Similarly, TZM molybdenum alloy was sufficiently developed and tested to allow leading-edge component fabrication for use up to 3000°F. New processing, fabrication, and inspection techniques required for these new materials were also developed. A major effort involved qualification of materials and components, such as window materials, for use at 2000°F, thermal insulations to 3000°F, and antifriction bearings to 1800°F. Thus, the materials and structural component state of the art was significantly advanced during the X-20 program.

Rene' 41 Hot Structure

At the advent of the X-20 it was apparent that conventional aircraft structural materials would not meet the design thermal environment imposed by lifting entry. Attention was immediately focused on the nickel and cobalt superalloys which retained significant strength properties at elevated temperatures. Rene' 41 was selected as the most efficient material available, and design-allowable mechanical properties, processing, and fabrication techniques have been developed for it.

Designs of efficient, minimum-weight structural members have been developed through the use of such processes as swaging of tubes, chem milling reinforcements, and fusion and resistance welding of assemblies. Heat treatment processes have been optimized and defined to obtain the best strength and ductility properties over a wide temperature range. Both welded and bolted joints have been developed for truss members and have been used separately or in combination, depending on deflection-induced stresses.

These developments currently allow the design and production of aircraft-quality primary structural components capable of efficient performance at temperatures up to 1800°F.

Control Surfaces

Relatively thin control surfaces make a determinate truss structure inefficient and impractical for this application. Therefore, a semimonocoque structure, capable of accommodating thermal gradients, was developed for the X-20. Design, fabrication and testing to simulated entry conditions was accomplished on a two-cell Rene' 41 corrugated web box. Testing demonstrated the feasibility of using a multicell torque-box hot structure for control surfaces.

The X-20 elevon, a three-cell torque box as released for production, is currently being fabricated and will be load and heat tested to the elevon design environment under an X-20 continuation contract.

Landing Gear

An energy absorption system capable of operating efficiently throughout the temperature range of 70 to 800°F was developed to production status during the X-20 program. Inconel was selected as the most suitable material from the standpoint of energy absorption capacity, stress-strain curve shape, elongation characteristics, and strength properties. This material exhibits large, plastic strain characteristics of a uniform nature, and minor variation in mechanical properties over the required temperature range at strain rates up to 300 in./in./min. as shown in Figure 11. Landing impact energy is absorbed by plastic deformation of the strap. Complete design-allowable stress strain curves at various temperatures and strain rates have been developed for this material and are available for the design of energy absorption systems.

Insulated Surface Panels

The development of concepts for heat shields culminated in fabrication and testing of complete insulated panel assemblies. Columbium (D-36) heat shields using a standoff clip design were attached to the corrugated Rene' 41 load-carrying panel. An insulation layer of Q-felt provided the necessary temperature reduction to the Rene' 41 structure. The assembly was exposed to a combination of design sonic excitation and temperature as shown on the chart. Plasma jet testing of an assembly simulating the junction of four heat shields demonstrated adequate control of leakage. Additional testing performed under the X-20 continuation contract of a nine-tile panel assembly in evacuated conditions has shown that analytical prediction of internal temperatures are in excellent agreement with test results. The test sequence subjected this panel assembly to the equivalent of five entries. Field repairs of the coating using the Boeing-developed coating repair process was successfully demonstrated during this series of tests.

Leading Edge

Leading-edge components have been developed and successfully subjected to simulated boost and entry conditions. Concept development on the X-20 program centered around single- and double-shell designs, both of molybdenum alloy. Each concept was

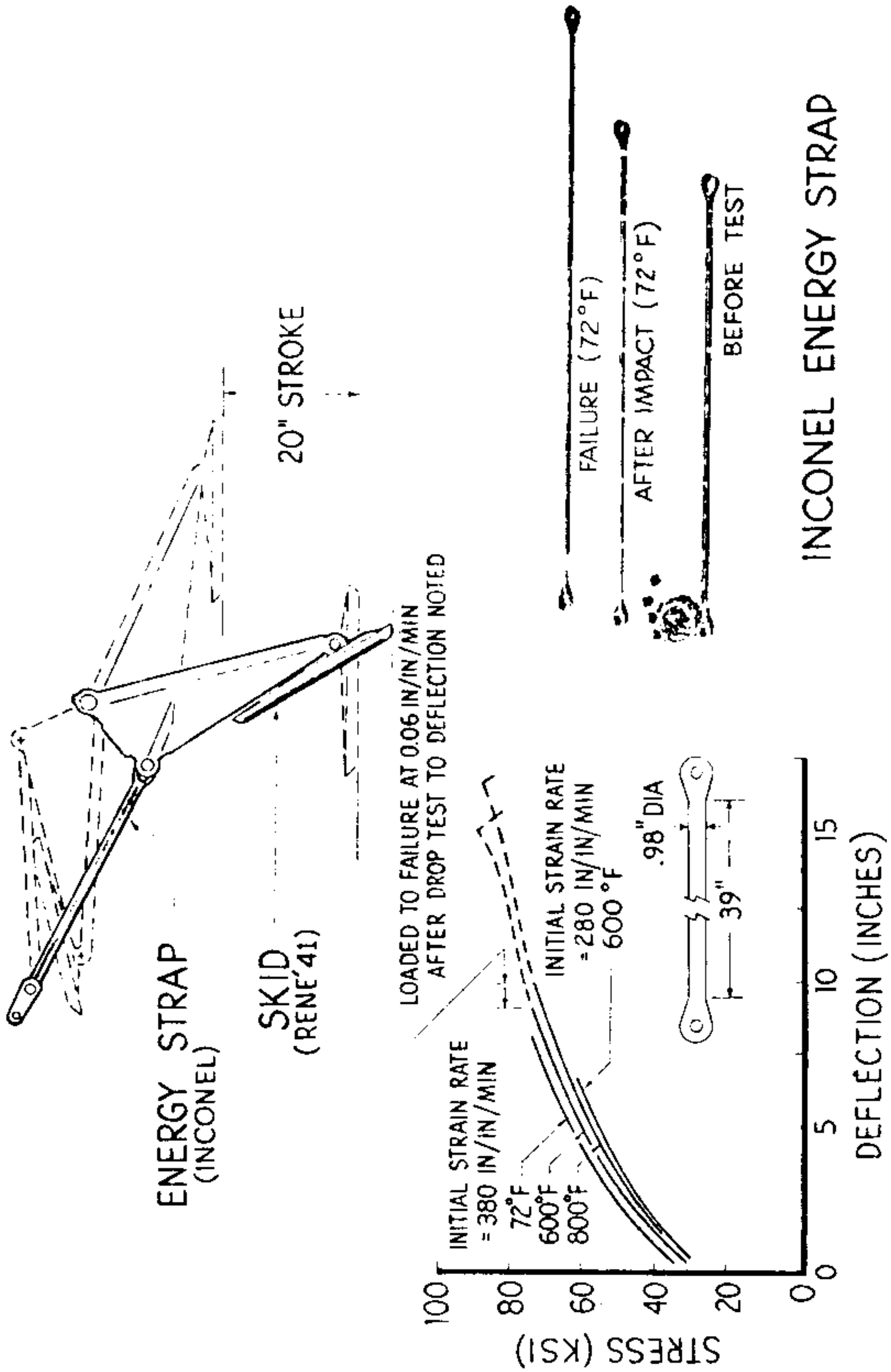

Figure 11

Landing Gear

developed to the stage where it successfully survived the equivalent of four complete boost and entry cycles of the X-20 flight regime. These tests not only verified the entry capability of the leading edge but also indicated multiple use capability.

Later material developments showed that slight additions of zirconium to the 0.5Ti-molybdenum alloy gave improved properties--particularly higher recrystallization temperatures. This new alloy, TZM, was used for all production-released molybdenum alloy hardware.

Integrated vehicle structural requirements, such as limitations on steps and gaps between leading edge segments, internal structural load deformations, fabrication tolerances, and material characteristics, indicated that the X-20 structural requirement best could be met by a simpler, although somewhat heavier structural concept. The revised concept consisted of a single TZM chemically milled shell. The chemical milling permitted use of integral stiffeners. The shell was supported by machined D36 (columbium) fittings.

Design Limits of Refractory Alloys

The design and development program also served to identify design limits of refractory alloys. There were, of course, the obvious design constraints associated with the necessity of applying a protective coating. The principal limitation on columbium alloys is the tendency to creep at high temperature, greatly reducing their load-carrying capability. Minimum gages (0.014-inch for molybdenum alloys and 0.012-inch for columbium alloys) were established to assure sufficient material for oxidation protection of the edges.

The room-temperature ductility of TZM, which is not very high in the bare material, is considerably reduced by the coating process. This lowered ductility manifests itself in making fabrication and assembly of parts difficult and dictated extremely tight control of dimensional tolerances during coating. Programs under way at the time the X-20 was canceled indicated that controlled heat treatment could reduce the problem.

Thermal exposure (above 2000°F) recrystallizes TZM (and other molybdenum alloys), which in turn lowers the room-temperature ductility of the alloy. This can be seen at the bottom of the chart in terms of grain growth in the photos, and transition from ductile to brittle impact failures, as the material reaches 100-percent recrystallization. This required that the TZM components be designed as "brittle" materials through the landing phase.

Coating Processes and Refractory Alloy Components

The selection of refractory alloys was predicated on the development of a production process for application of oxidation resistant silicide coating. The fluidized bed technique was developed for this purpose. In this technique the parts to be coated are suspended in a bed of silicon powder that has been heated to the required reaction temperature. The silicon is made fluid by passing a mixture of argon and a reacting halide gas up through the bed. This facility not only gives a uniform coating, but is a rapid production method in that it eliminates the long heat-up and cool-down with associated retort-furnace methods. In addition to coating X-20 parts, the fluidized bed technique has been used to coat parts for the ASSET vehicle and to coat experimental rocket nozzles and thrust chambers.

Two production fluidized beds capable of coating parts 17 inches in diameter and up to 3 feet long were built and qualified for the X-20 program. Processes were developed for coating both

D-36 (columbium) and TZM (molybdenum) components. Although the coating temperatures and times varied for the two alloys, the basic techniques of cleaning, inspecting, and coating were the same. The cycle was split for most components, half the coating being applied to detailed parts before assembly and half after assembly. This procedure afforded protection of faying surfaces and ensured coating of areas where coating damage had occurred during assembly.

An important adjunct to the coating process was the development of emittance improvement coatings, applied over the silicide oxidation protective coating. A Synar-silicon carbide was used for D-36. Because of the low emittance of silicide-coated D-36, and the significant improvement obtained, the top coat was applied to all exterior D-36 surfaces. A similar technique was developed for TZM. Evaluation of this process is continuing under an X-20 continuation contract.

Entry Capability of Coated Refractory Alloys

The allowable time-temperature capability of coated refractory alloys when exposed to an X-20 type entry has been established through extensive testing and analysis. In these tests the critical parameters, temperature, pressure, and atmosphere composition were simulated. Numerous tests were conducted extending through and beyond the predicted design environment. Besides normal entry conditions depicted on the chart, the tests included evaluation of abort trajectories, simultaneous load oxidation tests, and parametric environmental tests. Analysis after exposure included extensive metallurgical evaluations of coating and base metal integrity.

These tests and analyses have provided a great deal of information about coating-metal and coating-environment reactions.

Models developed for predicting the nature and rate of these reactions have provided the basis for predicting the performance of coated refractories in environments that differ from the X-20 entry conditions. Allowable time-temperature curves similar to those shown in Figure 12 could be readily developed for other design trajectories.

Nose Cap

At the conceptual stage of X-20, the nose cap (shown in Figure 13) was determined to be one of the most crucial problem areas. For this reason two independent development programs were initiated. Both were successful. The primary design was the Ling-Temco-Vought cap and the backup design was the Boeing cap. The primary design was composed of a structural siliconized-graphite shell, protected by zirconia tiles held in place by zirconia pins. The pins and tiles were reinforced by platinum-rhodium wire so that the cracks would not cause total failure. The backup design was a monolithic structure composed of zirconia reinforced with platinum-rhodium wire in the form of shaped baskets. Hexagonally shaped tiles were induced in the outside surface in the forming process to allow for thermal expansion and act as crack stoppers. Attachment to the glider structure in both cases was similar. A forged molybdenum (TZM) ring with a clamping action was used. Molybdenum rivets, nuts, and bolts were developed for attaching the ring to the Rene' 41 truss assembly. Both caps contained flight-pressure ports and high-temperature thermocouples. Full-size nose caps were fabricated for testing because conventional scaling methods are not satisfactory for ceramic components.

Both concepts were verification tested in plasma jet, ram jet, rocket exhaust, oxy-propane burner, and random noise facilities.

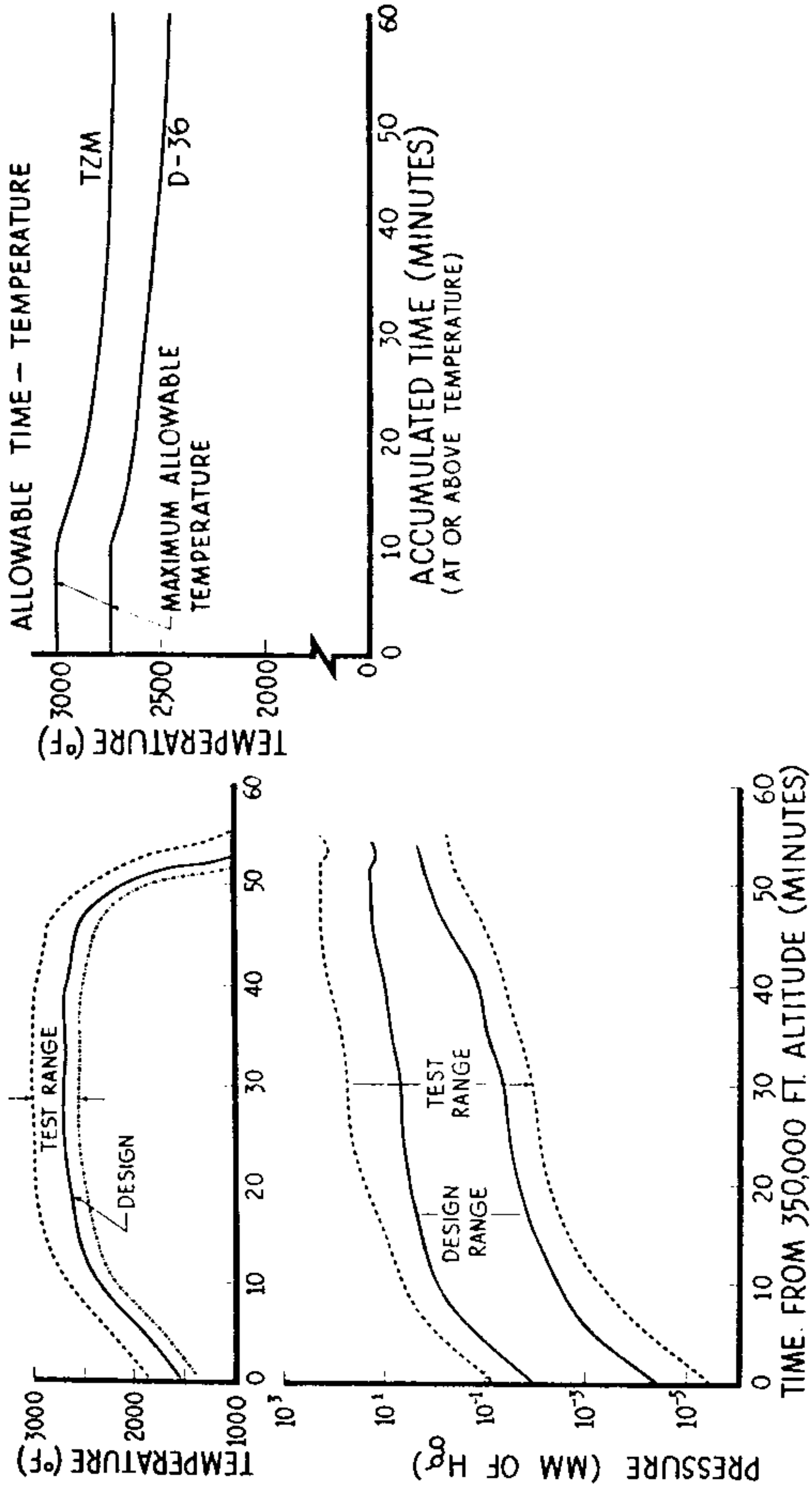

Figure 12

Entry Capability of Coated Refractory Alloys

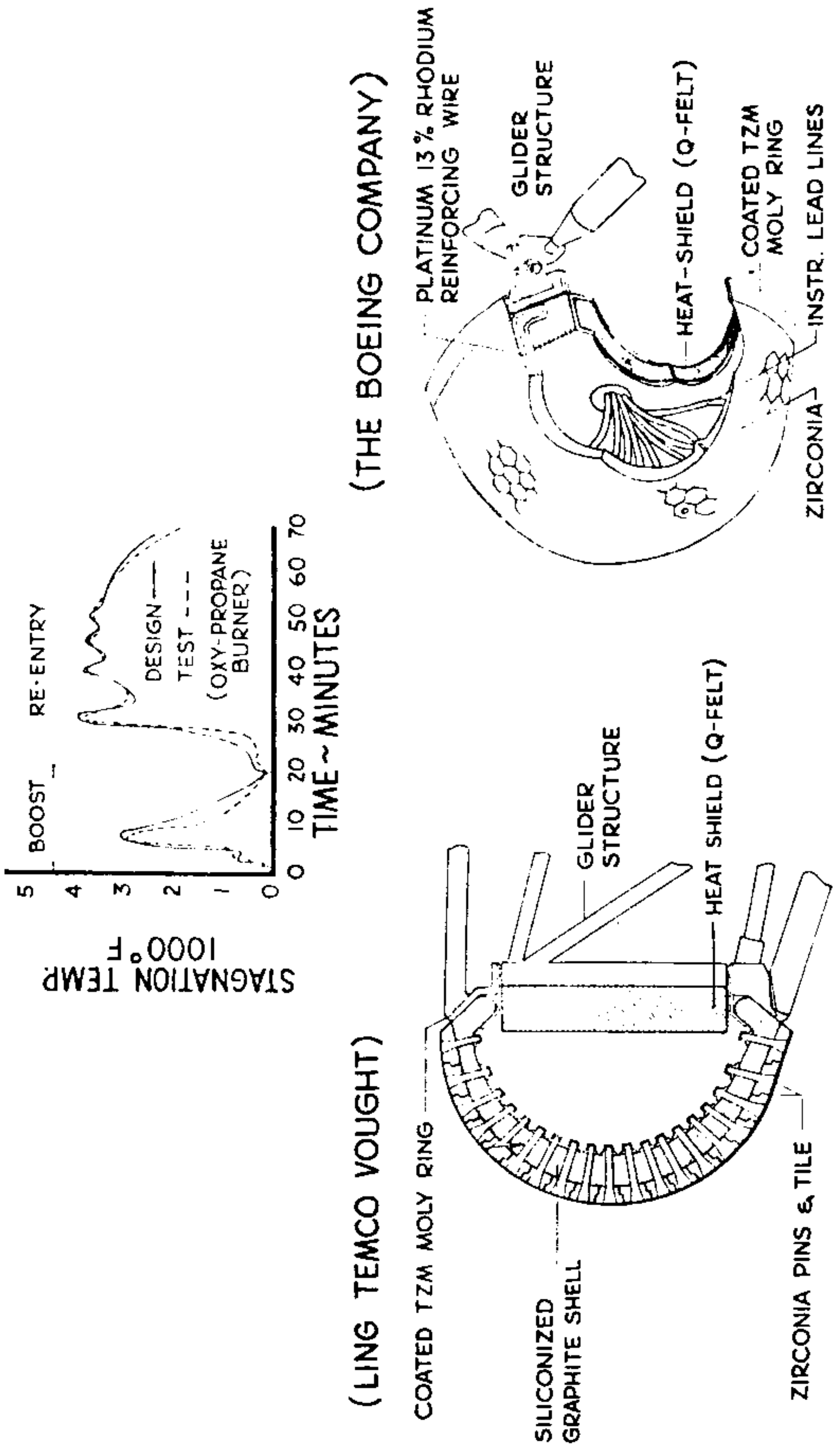

Figure 13
NOSE CAP

Simulation of all design points corresponding to the X-20 environment proved both nose caps adequate for flight. These tests further demonstrated that the design and fabrication methods used were satisfactory.

High-Temperature Thermal Insulations

A two-way program was followed for development of thermal insulations for the X-20 program. Commercial fiber insulations were evaluated to determine if their use temperature could be extended beyond the 2000°F recommended by the manufacturers. Results of this program established the temperature limits of the insulations as shown. Laboratory techniques for production of alumina and zirconia fibers were scaled up in an attempt to produce a new high-temperature insulation. A pilot production facility was completed that successfully produced fibers having the desired temperature capability and conductivity. First attempts to put the fibers into a usable form showed promise, but the program was canceled when it was determined that commercial insulations would meet X-20 requirements.

Tests determined the upper temperature limit for nearly all commercial high-temperature insulations. The most significant of these tests was evaluation of shrinkage when the insulation was exposed to various temperatures up to 3000°F. Extreme shrinkage resulted at temperatures below 3000°F for all materials tested except for a quartz fiber known as Q-felt. A small dimensional change was observed by Q-felt at about 2000°F with no additional change to over 3000°F. It was therefore possible to stabilize this material by pre-exposure to 2000°F.

Figure 14 shows complete conductivity design data developed for the stabilized material up to its maximum use temperature.

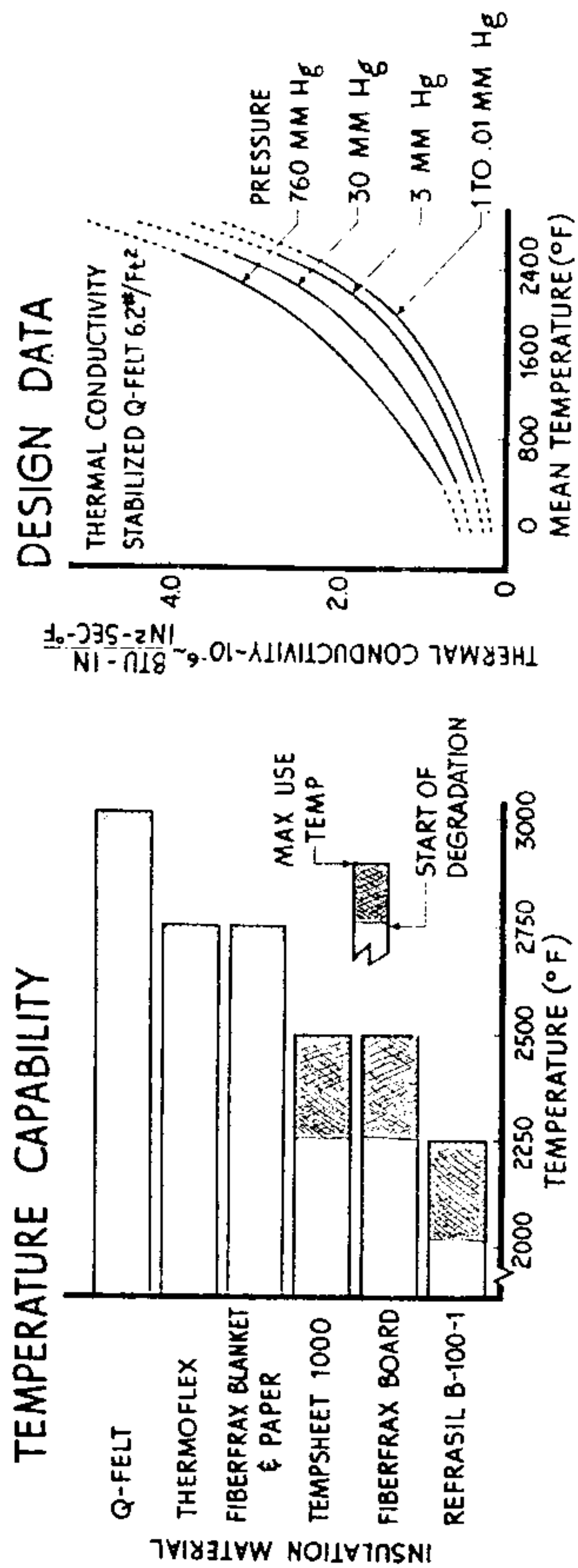

Figure 14

High Temperature Thermal Insulations

Other Structural Developments

Many other significant advances were made in structural subsystems, components, test techniques, design property data, measurement techniques, instrumentation development, fabrication techniques, and other detail design items.

High-temperature windows and window-mounting materials, window-mounting techniques, flightweight cryogenic tanks having superinsulation, and high-temperature antennas and wave guides will apply to future entry systems. High-temperature fastener development, high-temperature hydraulic fluids, instrumentation, high-temperature aerodynamic seals, and a multitude of other design detail items will also make important contributions.

Immediate benefits will result from use of design property data and measurement techniques developed. Techniques such as the use of an electron beam for heating zirconia to 4000°F to determine emittance values can be applied to the evaluation of other high-temperature materials. The mechanical and physical properties developed for Rene' 41, 2219 aluminum, coated refractory alloys, zirconia, fasteners, and insulations are also available.

Landing Skids

The X-20 landing gear was a tricycle, metal-skid configuration able to survive the entry heating environment without thermal protection. The main skids were designed to generate a higher friction coefficient than the nose skid. The higher friction coefficient was required for the main skids to provide ground slide-out stability, especially at the lower speeds when aerodynamic forces are ineffective. The skids, designed for use on concrete, asphalt, and dry lake beds, were replaceable after each flight.

The main skids were a Goodyear design and were formed and welded of Waspoloy sheet metal with Rene' 41 wire bristles twisted over a series of longitudinal rods. Since the wire brush was inherently able to handle runway irregularities in the roll axis, the skid pivot attachment design allowed motion in the pitch axis only. The wire brush design gave a high friction coefficient with 5000 to 8000 feet of slide-out distance.

The nose skid was initially a Bendix design and was formed and riveted of inconel with tungsten carbide hard coat on the sole plate for wear. The final design, with the sole plate, was forged of Rene' 41. The skid-pivot attachment allowed pitch and roll of the skid over irregular surfaces and prevented yaw. A nose ramp allowed sliding over sharp bumps.

Skids were tested on the Holloman AFB rocket sled. The test sled could simulate landing impact and slide-out loads. Test surfaces were concrete and asphalt. The main skids were also tested at Edwards AFB with a modified X-15 skid-test trailer towed behind a B-47. Tests were at speeds up to 120 knots on lakebed and concrete runways. Figure 15 shows the skid test results.

Hydraulic Servoactuator

X-20 flight control required the use of control surfaces throughout entry. A hydraulic system was chosen for surface actuation to minimize development time and cost. Because the X-20 operated with temperatures above 1800°F during entry, the hydraulic system was designed to be cooled using the hydraulic fluid as the initial heat transport medium. Final heat rejection to the hydrogen heat sink was through the intermediate water-glycol cooling loop.

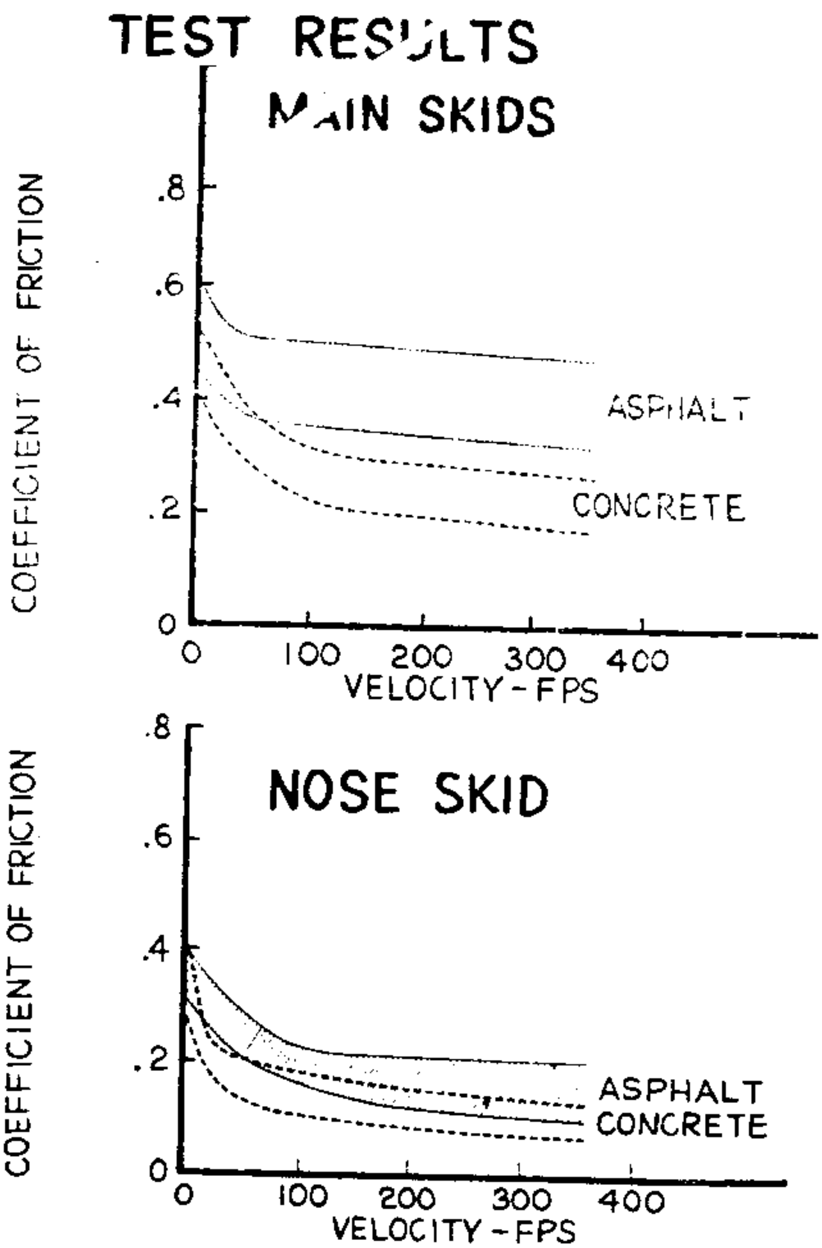

Figure 15

Landing Gear Skid Test Results

The 400°F hydraulic fluid operating temperature eliminated the need for a major advance in the state of the art in fluids, transducers, and servovalves. All hydraulic system components except surface actuators and associated plumbing were located in a cooled compartment to hold entry heat loads to a minimum. The surface actuators and plumbing exposed to high temperatures were insulated with a 1-inch "Q-Felt" blanket. The actuator and components were cooled by circulating return hydraulic fluid through the jacket and rod. The coolant flow required did not exceed that required for normal surface control; hence, there were no additional pumping loads. The dual rod seal was developed to provide high system reliability.

A prototype actuator including the insulation and cooling jacket was successfully tested through entry and altitude environment. These tests showed close agreement between predicted and measured temperatures at critical points throughout the actuator. The dual rod seal was successfully tested through a 100,000-cycle life test at fluid operating temperatures of 20°F to 550°F.

Water-Wall Development

One of the major X-20 accomplishments was the successful development of a water-wall to thermally isolate the pilot's compartment, equipment bay, and secondary power bay from entry-generated heat. The water-wall heat sink was a gel mixture of 95 percent water and 5 percent cyanogum 41 jelling agent contained in a series of wicks. The purpose of the gel-wicking arrangement was to maintain proper distribution of water in the panels under boost, space, and entry conditions.

The water-wall was of lightweight construction weighing approximately 0.14 psf empty. The panel thickness varied with the water capacity and was approximately 0.31 inch for a water capacity of 1 psf. The outer insulation layer thickness was 0.5 to 0.75 inch depending on the application. The water-wall relief valves opened at approximately 0.5 psig. The water panel temperature increased from approximately 50°F at maximum altitude to 200°F at sea level as the evaporation temperature increased with atmospheric pressure.

Water panels of this type can be used on either radiant or ablative cooled entry systems. However, the X-20 did not require space storage so further development would be required to attain this feature.

Integrated Hydrogen Cooling and Power Generation System

The X-20 cooling and power system used cryogenic hydrogen for auxiliary power unit fuel and as a heat sink in controlling glider internal temperatures. The system consisted of the following major elements, and is shown in Figure 16.

1. Tanks for storage of cryogenic hydrogen and oxygen.
2. A primary hydrogen/glycol-water heat exchanger.
3. Redundant glycol-water cooling loops to transfer heat from the cooled compartments, hydraulic fluid, alternators, and auxiliary power units to the primary cooler.
4. Related plumbing and controls.
5. Redundant auxiliary power units.

This system required the development of flightweight vacuum insulated plumbing and tanks as well as various system mechanical components. These developments are applicable to other cryogenic systems.

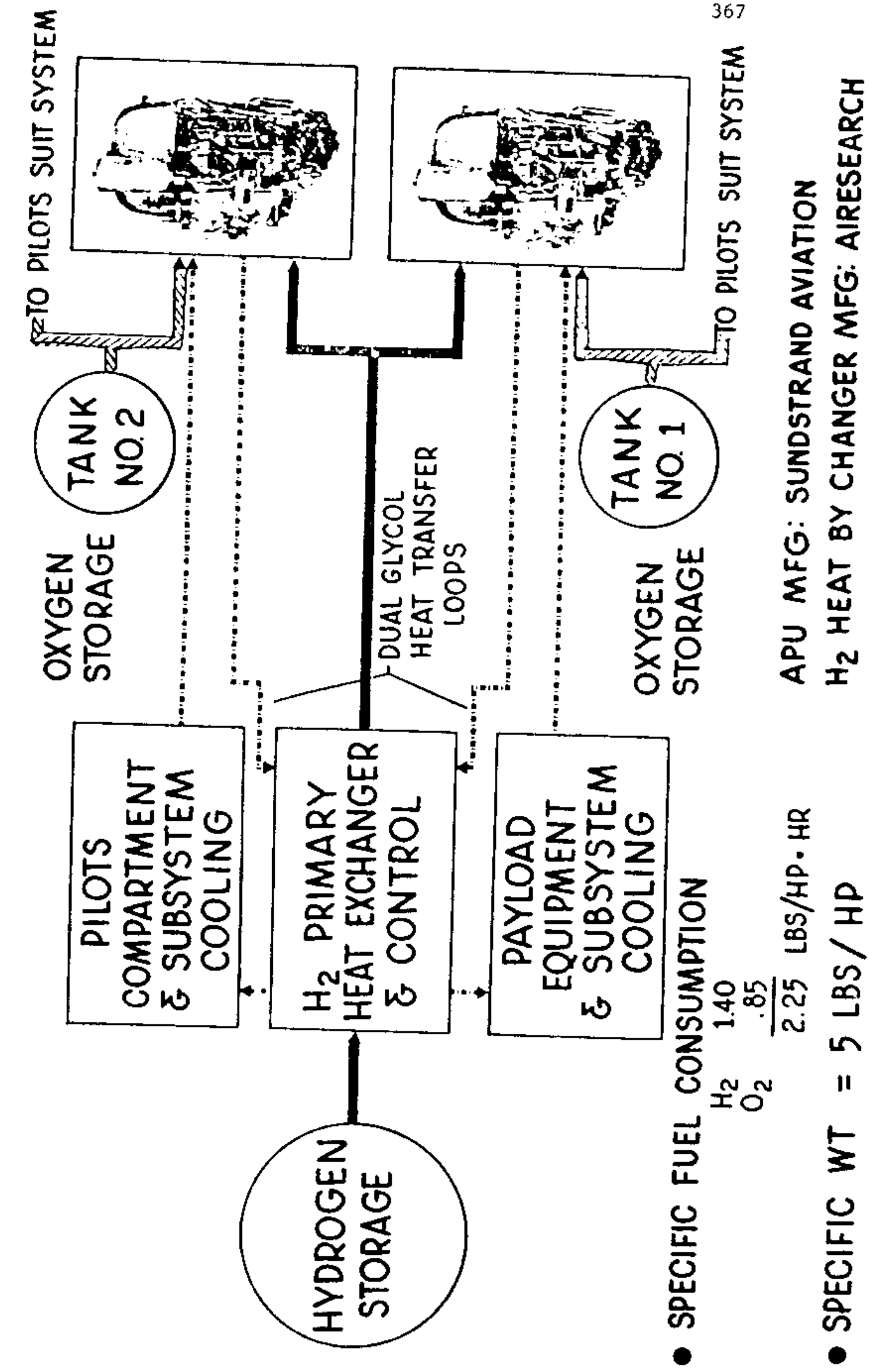

Figure 16

Integrated Hydrogen Cooling and Power Generation System

The auxiliary power unit consisted of a unique hydrogen/oxygen powered, three-stage single disc turbine that drives hydraulic and electrical power generating equipment. The turbine uses a catalytic combustor and has a zero-g lubricating system. The hydraulic pumps were designed to operate at temperatures up to 400°F and delivered 8.5 gpm at 3000 psi. The 12-kva electric alternators were liquid cooled and were the first rotating electrical power source specifically designed for space use.

Personnel Protection

To provide pilot protection in a potential vacuum environment and to meet other X-20 requirements, a new space suit was developed through the combined effort of USAF-ASD and the David Clark Company. The integrated suit assembly included gloves, helmet, boots, communication equipment, biosensors, ventilation, underwear with special joints, insulation, and restraint and parachute harness. The final suit configuration was the result of extensive testing in environmental chambers and flight simulators to evaluate suit growth, weight, back pressure, ventilation, mobility, and leak rate. This program resulted in a suit that can be pressurized to 5 psi and still exhibit good flexibility with minimum growth. It is also suitable for other space applications. The suit offered the following advantages over previous designs:

- Head moved within helmet, offering improved mobility and field of vision.
- Minimum helmet rise under pressure, eliminating tiedown straps.
- Excellent arm and leg mobility while seated at 5 psi pressure.
- Suit retained its external dimensions at 5 psi pressure, and shoulder width remained less than 25 inches.

Crew Station and Side Arm Controller

The X-20 crew compartment was a welded aluminum structure pressurized to 7.35 psia. Specific design features in the crew station were: (1) high-temperature windshields for pilot vision, (2) provisions for full pressure suit operations and the associated reach problems, (3) an ejection seat positioned for boost, entry, and ejection conditions, (4) a side arm flight controller and rudder pedals, and (5) instrument displays to satisfy orbital flight, entry from orbit, maneuverability during hypersonic glide, and controlled, unpowered landing at a predetermined site.

The side arm flight controller was a two-axis unit having minimum cross coupling in roll and pitch, and minimum sensitivity to acceleration forces. The controller operated both reaction controls and control surfaces. The crew station arrangement and the side arm controller were developed through extensive simulation and piloted centrifuge programs in which Air Force and NASA astronauts participated. These programs included operation under pressurized suit conditions and pilot-in-the-booster-loop simulations.

Although this crew station was designed specifically for the X-20, the final arrangement can provide background data and design features applicable to future lifting entry vehicles.

Boeing X-20 Continuation Program

Many hardware development tasks pursued as a part of the X-20 program represented substantial advances in the state of the art in a wide variety of technical areas. The same was true for many purely analytical development tasks. Because of their potential value in other programs, a number of these partially completed tasks were authorized to be completed. This effort was designated as the X-20 continuation program.

The following is a listing of the number of X-20 reports generated by Boeing and subcontractor organizations, followed by remaining continuation tasks and the expected dates of completion.

		QUANTITY
BOEING DOCUMENTS		1255
ENGINEERING	1050	
WIND TUNNEL	155	
FACILITIES	12	
MANUFACTURING	19	
PROGRAM MANAGEMENT	19	
SUBCONTRACTOR DOCUMENTS		1780
AIRESEARCH	207	
BELL	33	
ELECTRO-MECHANICAL	344	
LING-TEMCO-VOUGHT	129	
MINNEAPOLIS-HONEYWELL	582	
SUNSTRAND	240	
THIOKOL	177	
THOMPSON-RAMO-WOOLDRIDGE	23	
WESTINGHOUSE	45	
TOTAL X-20 DOCUMENTS		3035

NO.	ITEM	TASK	COMPLETION DATE
2-6	D36 EROSION SHIELD PANEL	TEST & EVALUATE	9-30-64
2-3	HIGH TEMPERATURE BEARINGS	DETERMINE LOAD/LIFE CHARACTERISTICS	5-31-65
----	L-T-V NOSE CAP	COMPLETE DEVELOPMENT TEST	COMPLETE
2-5	BOEING NOSE CAP	COMPLETE DEVELOPMENT TEST	7-31-64
2-12	ELEVON STRUCTURE	VERIFY STRUCTURAL INTEGRITY	1-15-65
5-3	PILOTS COMPARTMENT	LEAK & PROOF PRESSURE TEST	11-30-64
5-3	EQUIPMENT COMPARTMENT	LEAK & PROOF PRESSURE TEST	11-30-64
1-9	GUIDANCE & CONTROL MODEL	INSTALL AT WRIGHT FIELD FOR USAF	12-11-64
2-9	HIGH TEMPERATURE WINDOWS	VERIFY INTEGRITY OF SIDE WINDOWS	2-28-65
10-4	HEAT FLUX TRANSDUCER	DEVELOP INCIDENT HEAT FLUX SENSOR	4-30-65
10-4	LOW PRESSURE GAS MEASUREMENT	DEVELOP HIGH TEMP. -LOW PRESS. MEASURING SYSTEM	4-30-65
10-4	ULTRA VIOLET DENSITOMETER	DEVELOP AIRBORNE DENSITY MEASURING SYSTEM	4-30-65
10-4	HIGH TEMP. FLUTTER TRANSDUCER	DEVELOP 1400°F FLUTTER SENSOR	4-30-65
6-2	HYDROGEN TANK	ASSEMBLE & ACCEPTANCE TEST	10-31-64
6-3	OXYGEN TANK	ASSEMBLE & ACCEPTANCE TEST	10-31-64
6-5	H_2 SERVICING SYSTEM	ASSEMBLE & FUNCTIONAL TEST	10-31-64
6-6	O_2 SERVICING SYSTEM	ASSEMBLE & FUNCTIONAL TEST	10-31-64

1-1	CONTROL SURFACE BUZZ MODEL	ASSEMBLE FOR USAF TESTING	6-30-64
1-4	FLUTTER ANALYSIS CORRELATION	DOCUMENT & CORRELATE FLUTTER DATA	8-31-64
1-5	PANEL FLUTTER FLIGHT TEST	REPORT ON X-20 PANEL TESTS ON F-104	10-30-64
1-6	20% GROUND VIBRATION MODEL	COMPLETE MODEL & PERFORM TESTS	9-30-64
2-1	COMPUTER PROGRAMS	DOCUMENT 5 X-20 COMPUTER PROGRAMS	8-25-64
2-2	BOOST WINDS CRITERIA	DOCUMENT BOOST PHASE ANALYSIS	7-31-64
3-1	MATERIALS DEVELOPMENT	DOCUMENT MATERIALS ACCOMPLISHMENTS	1-30-65
----	WEIGHTS ANALYSIS REPORT	DOCUMENT WEIGHT ANALYSIS METHODS	8-1-64

The following references are supplied to furnish readers with a selected bibliography of key X-20 technical reports.

X-20 References

Static Stability

D2-80065 — Aerodynamic Stability and Control Data, Model 844-2050

D2-8083 — Glider Stability and Control Analysis, Model 844-2050

Aerodynamic Interaction Effects

ASD-TDR-63-148 (Vol. II) — Configuration Evolution Due to the Influence of Stability and Control

Hypersonic Aerodynamics

D2-8080-1 — Glider Performance Characteristics Report

Laminar Theory and Data Improvement

D2-90138	Error Analysis and Methods for Correction of Thin Skin Heat Transfer Model Data

Turbulent Heat Transfer

D2-8108	Preliminary Aerothermodynamic Analysis Report
D2-8108-1	Addendum to Aerothermodynamic Environment Analysis Report

Detail Design Heating

D2-8108	Preliminary Aerothermodynamics Analysis Report
D2-8108-1	Addendum to Preliminary Aerothermodynamics Analysis Report

Hypersonic Maneuver Capability

D2-8080-1	Glider Performance Characteristics Report
D2-8083	Glider Stability and Control Analysis, Model 844-2050

Energy Management Display Indicator

D2-8080-1	Glider Performance Characteristics Report
D2-8088-5	Mission Guidance and Energy Management Analysis Report
D2-8143-1	Energy Management Display Study
D2-80073	Energy Management Overlay Analysis
D2-80869	Construction and Use of Dyna-Soar Energy Management Overlays

Adaptive Gain Computer Performance

D2-8129	Glider Flight Control Subsystem Analysis Report
D2-8083	Glider Stability and Control Analysis, Model 844-2050

Piloted Boost Simulation

D2-80762 (Vol. I)	Pilot in the Booster Control Loop Study - Final Report

Structural Component Advancement

D2-81261 X-20 Engineering Summary Report of Structures and Material Technology

Rene' 41 Hot Structure

D2-80081 Primary Structure Development LT5-652, Shear Web and Panel Tests

D2-80272 Riveted and Bolted Joints of Refractory and Super Alloys

D2-80277 Heat Treatment of Rene' 41

D2-80278 Resistance Welding of Super Alloys

D2-80279 Fusion Welding of Super Alloys

D2-81242 Internal Loads Program

Control Surfaces

D2-80082 Control Surface Development - Dyna-Soar

D2-80084 External Surface Panels (Noninsulated) Development - Dyna-Soar (Vol. I and II)

Landing Gear

D2-80086 Landing Gear Development

Insulated Surface Panels

D2-80080 Insulated Panel Development

D2-80876 External Surface Seal Development

Leading Edges Development

D2-80085 Leading Edges Development

Design Limits of Refractory Alloys

D2-80275 Ductility of Silicide Coated TZM Molybdenum Alloys

D2-81113-1 Design Requirements for Coated Refractory Alloys

D2-81113-2 Design Requirements for Coated Refractory Alloys

Coating Processes for Refractory Alloy Components

D2-81108-1	Development of Oxidation Resistant Coatings for Columbium Alloys - Fluidized Bed Process
D2-81108-2	Development of Oxidation Resistant Coatings for Columbium Alloys - Vacuum Pack Process
D2-81109	Development of Oxidation Resistant Coatings for Molybdenum
D2-81110	Emittance Improvement Coating Development for Refractory Alloys (Vol. I and II)

Entry Capability of Coated Refractory Alloys

D2-81111-1	Performance of Oxidation Resistant Coatings for Columbium Alloys
D2-81111-2	Performance of Oxidation Resistant Coatings for Columbium Alloys
D2-81112	Performance of Oxidation Resistant Coatings for Molybdenum (Vol. I and II)

Nose Cap

D2-80083	Nose Cap Development Testing
D2-80287	Material Development Program, Boeing Nose Cap, X-20
D2-80608	Fabrication of the Boeing Nose Cap

High Temperature Thermal Insulations

D2-80283	Development Programs, Thermal Insulations, X-20
D2-80755	Ceramic Fiber High-Temperature Thermal Insulation Development

Other Structural Developments

D2-80088	Window Development - Dyna-Soar
D2-80092	Cryogenic Tanks Development - Dyna-Soar
D2-80270	Welding of Columbium Alloys
D2-80281	Thermal Properties Measurement Techniques
D2-80284	Window Materials Development

D2-80535	Fabrication Requirements for Cryogenic Tanks
D2-80670	Fabrication of Columbium Alloy Antennas for X-20A
D2-80876	External Surface Seal Development Test

Landing Skids

D2-80777	Test and Data Report - Dyna-Soar Landing Gear High Speed Development Test

Hydraulic Servoactuator

D2-80280	Hydraulic Fluids Evaluation
D2-81020	Test Report - First Elevon Prototype Servo Actuator
D2-81021	Test Report - Guidance and Control Development Model, X-20 Elevon Hydraulic Power Servos
D2-81033	Hydraulic Tubing and Fitting Evaluation Test Progam
D2-81034	Hydraulic System Metallic and Elastomeric Seal Evaluation Test
D2-81096	Development of Insulated Hydraulic Tubing and Servo Wiring Assemblies

Water-Wall Development

D2-80603	Water-Wall Construction
D2-80803-2	Qualification Test Report for Water-Wall
D2-80812	Water-Wall Development Testing Report

Integrated Hydrogen Cooling and Power Generator System

D2-80001-3 (Vol. I and II)	Analog Computer Simulation of the Dyna-Soar Glider Integrated Environmental Control and Secondary Power Subsystems
D2-80448	Cryogenic Subsystem Design Development Tests
D2-81138 (Vol. I and II)	Breadboard Cryogenic Development Test Results

NOTES

1. Aero-Space Division, The Boeing Company, Summary of Technical Advances: X-20 Program, D2-23418 (Seattle, WA: The Boeing Company, July 1964), passim. For the benefit of the reader, I have numbered the figures, deleted extraneous material, and consolidated the references according to subject. This report, now unclassified, is in the Shuttle records collection of the NASA Lyndon B. Johnson Space Center in the "July 1964" file. This collection of material, assembled by former NASA LBJ Historian Jim Grimwood and archivist Sally D. Gates, is part of a collection of material recently transferred to Rice University as part of a NASA-Rice archives agreement. I wish to acknowledge my debt to Mr. Grimwood and the late Sally Gates for their assistance during my research into the Johnson Space Center records collection.