History of Rocketry and Astronautics

Proceedings of the Twenty-Second and Twenty-Third History Symposia of the International Academy of Astronautics

Bangalore, India, 1988
Málaga, Spain, 1989

John Becklake, Volume Editor

R. Cargill Hall, Series Editor

AAS History Series, Volume 17

A Supplement to Advances in the Astronautical Sciences

IAA History Symposia, Volume 10

AAS Publications Office
P.O. Box 28130
San Diego, California 92198

Affiliated with the American Association for the Advancement of Science
Member of the International Astronautical Federation

First Printing 1995

ISSN 0730-3564

ISBN 0-87703-395-1 (Hard Cover)
ISBN 0-87703-396-X (Soft Cover)

Published for the American Astronautical Society
by Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198

Printed and Bound in the U.S.A.

Chapter 17

The X-20 Space Plane: Past Innovation, Future Vision[1]

Terry L. Sunday[2] and John R. London, III[3]

In November 1957, the United States Air Force initiated an aerospace project that was one of the most innovative concepts of its day and also provided an accurate glimpse into the future. The X-20 space plane, known as *Dyna-Soar*, never reached operational status—it was canceled in December 1963 before the first prototype was built. But even though the diminutive vehicle never flew, technological advances made during its development laid the foundation for many later manned space systems, including some as new as tomorrow's headlines.

In 1961, the United States had in progress two major manned spaceflight programs. One, sponsored by the National Aeronautics and Space Administration (NASA), was the *Mercury* spacecraft under development by the McDonnell Aircraft Corporation in St. Louis, Missouri. The other, for the U.S. Air Force, was the *Dyna-Soar* space plane being built by the Boeing Company's Aero-Space Division in Seattle, Washington.

The two spacecraft could not have been more different. NASA's *Mercury*, popularly (and not without reason) called a "capsule," was a product of the nation's leading aerospace research-and-development organization. It emphasized scientific objectives over operational utility. The tiny, conical one-man spacecraft was little more than an intercontinental ballistic missile (ICBM) re-entry vehicle (RV) with a man inside. Its

[1] Presented at the Twenty-Second History Symposium of the International Academy of Astronautics, Bangalore, India, 1988.

[2] Systems Engineer, Martin Marietta Astronautics, El Paso, Texas. Member AIAA. Member Aviation/Space Writers Association.

[3] Adjunct Professor, Space Technology, Florida Institute of Technology, Las Cruces, New Mexico. Fellow BIS. Associate Fellow AIAA.

astronaut "pilot" had no control over his craft's destiny after an orbital flight, as it plunged on a ballistic trajectory through the searing heat of atmospheric re-entry to an ignominious parachute splashdown in the ocean.

In contrast, the initial specifications for *Dyna-Soar* were established by combat-experienced Air Force officers with military objectives firmly in mind. Their concept of a manned spacecraft resembled a space-faring aircraft. After an orbital mission, the sleek glider would re-enter the atmosphere under its pilot's control and land on a runway like an ordinary jet fighter. Conceived during the earliest days of the space age, *Dyna-Soar* was the Air Force's first attempt to translate into hardware its dreams of a manned military space system.

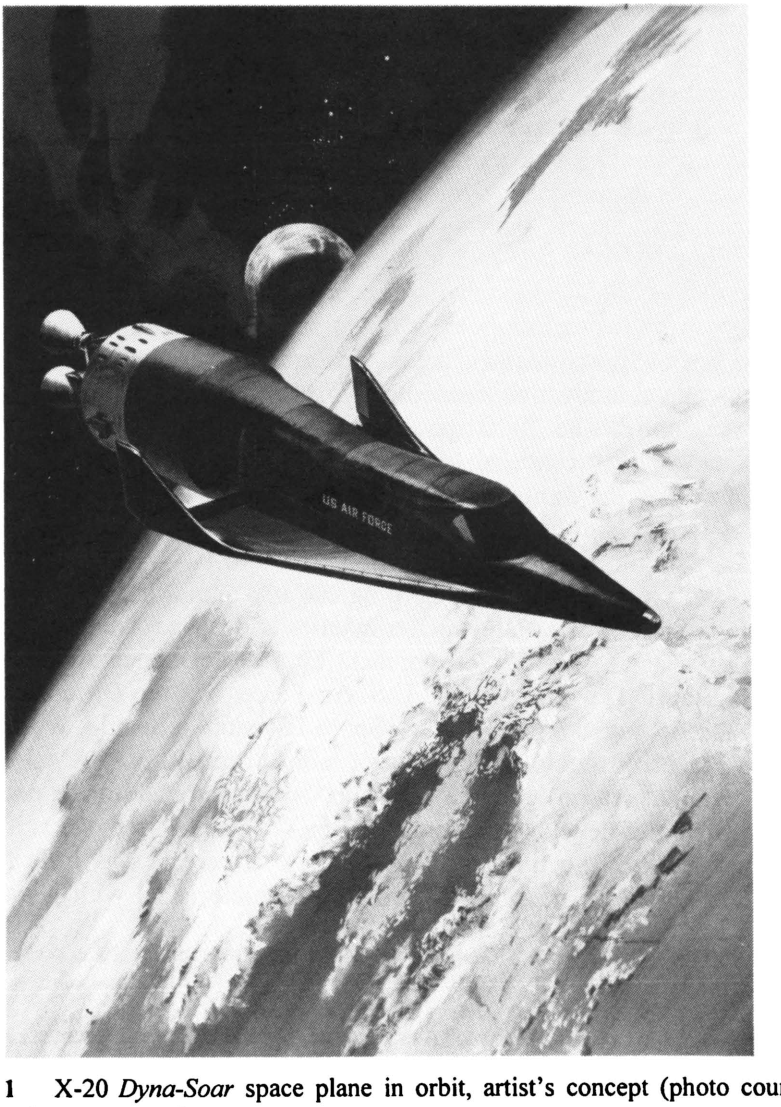

Figure 1 X-20 *Dyna-Soar* space plane in orbit, artist's concept (photo courtesy: Boeing Aerospace).

World War II Developments

The history of *Dyna-Soar* began late in World War II with the "antipodal bomber" concept developed by Austrian engineer/physicist Eugen Sänger and his mathematician colleague (later wife) Irene Bredt. The Sänger-Bredt bomber, conceived as an intercontinental weapon for the Third Reich, would have been able to strike U.S. targets from launch sites in Europe.

The 100-ton vehicle would have taken off like an aircraft after being accelerated to Mach 1.5 (on the ground!) in about 11 seconds by a captive rocket sled roaring along a three-kilometer-long horizontal track. Ascending under its own rocket power at a 30-degree angle, it would have entered a parabolic trajectory with a *Brennschluss* (burnout) velocity of about 6,000 meters per second, coasting up to a peak altitude of 160 kilometers. After dropping its 300-kilogram bomb load on New York City, or another selected U.S. target, it would have "skipped" off the atmosphere in a series of decreasing bounces to a point some 23,490 kilometers from its launch site—half way around the world at the antipodes. Its crew would have been picked up by submarine and returned to Germany.

The press of other wartime events and a lack of official interest, along with fierce competition within the Reich for critical war materials such as nickel, copper and chromium, prevented the antipodal bomber project from advancing beyond the study stage. In any event, its miniscule bomb load would have rendered it operationally useless.

Post-War Predecessors

After the war, the U.S. Air Force sought to expand its operational territory, then defined by the range and altitude capabilities of Strategic Air Command (SAC) bombers, into the new environment of space. The service believed the next global conflict could be decided in favor of the nation best able to control near-Earth space, and the design of *Dyna-Soar* reflected the belief that operations in space would be little different than operations in the air—just higher, faster and farther. A few years after the end of the war, some Air Force organizations took a serious interest in manned spaceflight. The Service sponsored several concept studies to try to define roles, responsibilities and hardware for what it saw as its mission in space.

The BOMI Concept

The first of these began in 1951, when the Bell Aircraft Company proposed a concept called BOMI (BOmber MIssile). Under conditions of great secrecy, the BOMI study was performed under the direction of Bell consultant Walter Dornberger, former *Wehrmacht* General and Commander of the Peenemünde rocket research establishment. The "Dornberger Project" proposed a manned, delta-winged, boost-glide vehicle similar to the antipodal bomber in that it would have been sub-orbital. On completing its bombing mission the craft would glide in to a runway landing. BOMI combined aspects of a missile (vertical launch, multiple stages) with those of an aircraft (controlled re-entry, runway landing)—the same design feature that would re-appear in the *Dyna-Soar* project nearly a decade later. BOMI would have operated at altitudes above 30,500 meters, at speeds over Mach 4, and would have been able to achieve a range of about 5,500 kilometers. Bell offered its BOMI proposal to the Air Force on 17 April 1952.

On 28 November 1952, the Air Force's Air Research and Development Command (ARDC) finished reviewing the proposal. Although it recognized that parts of BOMI duplicated on-going work on the *Atlas* ICBM and *Feedback* reconnaissance satellite studies, ARDC requested the Wright Air Development Center (WADC), at Wright-Patterson Air Force Base in Dayton, Ohio, to evaluate BOMI for manned bomber and reconnaissance missions. WADC completed its study on 10 April 1953, and rejected Bell's proposal for several reasons, including concerns about vehicle cooling, stability and control, and performance. WADC also thought BOMI's range capability was inadequate.

Bell refused to give up. Lobbying through ARDC Headquarters, the contractor persuaded WADC to reconsider BOMI. On 23 November 1953, WADC took a more favorable position, noting that a BOMI-like test vehicle could explore new flight regimes and serve as a predecessor for future manned, hypersonic systems. On 1 April 1954, WADC contracted with Bell for a one-year design study of an "advanced bomber-reconnaissance weapon system." The contract included a provision that "strategic requirements for an intercontinental vehicle" would be considered.

Over the next two years (the original contract period plus an extension), BOMI's predicted range capability increased, through steps of 9,250 and 18,500 kilometers, to "global" by November 1955. When the Air Force's BOMI funds ran out in early 1956, Bell had spent a total of $420,000 for concept studies and analyses. The project named BOMI then unceremoniously faded away, but the boost-glide vehicle concept remained alive.

System 118P, Brass Bell, ROBO and Hywards

On 4 January 1955, while the BOMI study was going on, ARDC issued System Requirement 12 (SR-12), which called for studies of a reconnaissance aircraft (or missile) with a 5,500-kilometer range capability and able to operate at altitudes of over 30,500 meters. In response, WADC initiated Special Reconnaissance System 118P. Since System 118P sounded exactly like BOMI, WADC brought Bell on board via a $125,000 extension to the existing contract on 21 September 1955. In Bell's BOMI Final Report, published on 1 December 1955, the System 118P vehicle was defined as a two-stage, Mach 15 rocket plane with an altitude capability of 50,000 meters.

On 12 May 1955, another concept surfaced, this one a result of the ARDC Intelligence and Reconnaissance Division's General Operational Requirement 12 (GOR-12). GOR-12 expanded on SR-12 by specifying a "piloted, high-altitude, reconnaissance weapon system . . . to be available by 1959." On 20 March 1956, the Air Force awarded Bell a $746,500 contract for Reconnaissance System 459L, commonly known as *Brass Bell*, which was designed to meet GOR-12.

Another boost-glide vehicle study resulted from an Air Force Request for Proposals (RFP) on 19 December 1955, which solicited "analytical investigations, proposed test programs, and design approaches for a manned, hypersonic, rocket-powered, bombardment and reconnaissance weapon system." Six companies responded to the RFP; Boeing, the Convair Division of General Dynamics, Douglas Aircraft, McDonnell Aircraft, North American Aviation and Republic Aircraft. Convair, Douglas and North American were awarded a total of $860,000 for study contracts running from May through December 1956. Bell, Lockheed Aircraft and the Martin Company later joined in, for what became ROBO (ROcket BOmber) on 12 June 1956, under ARDC SR-126. Designed to test the feasibility of a manned hypersonic vehicle, ROBO's main requirement was to "circumnavigate the globe" at an altitude as low as 30,500 meters.

In March 1956, yet another boost-glide vehicle requirement was formulated by the Research and Target Systems Division of ARDC. This one, unlike *Brass Bell* and ROBO, was for a research craft only, designed to provide data on aerodynamics, structures, subsystems and human factors to be used for the development of future hypersonic systems. The program, officially System 455L, was called *Hywards* (Hypersonic Weapons Research and Development Supporting System), ARDC issued *Hywards* SR-131 on 6 November 1956, and completed a development plan on 28 December.

Concept Consolidation

On 27 February 1957, the eve of the "space age," ARDC presented its plans for both *Brass Bell* and *Hywards* to Air Force Headquarters in Washington, D.C. Noting that the two proposed systems overlapped, Headquarters directed ARDC to consolidate them. While the objectives, requirements and technical approaches of the two concepts were merged into a combined boost-glide vehicle program, the funding requests were not added together. ARDC had requested $5,000,000 for *Hywards* and $4,500,000 for *Brass Bell* in Fiscal Year 1958 (FY58) allocations. Headquarters approved funding of $5,000,000 for the combined program. Before the funds became available, Headquarters changed its mind, disapproved the combined development plan and directed ARDC to prepare a new plan encompassing *all* hypersonic weapon systems.

Thus the final piece of the jigsaw puzzle of concepts that coalesced into *Dyna-Soar* fell into place. An *ad hoc* committee, meeting on 20 June 1957, and including representatives from ARDC, WADC, the Cambridge Air Force Research Center (CAFRC) and the Air Materiel Command (AMC), evaluated the ROBO study and concluded its development would be feasible only after a six-to-eight-year research period. Proposing a three-phase approach, the committee thought a hypersonic research craft (Phase 1) could be tested in 1965, a boost-glide vehicle (Phase 2) could be flying by 1968 and the full-up ROBO weapon system (Phase 3) could be available in 1974. The committee's proposal, with features of *Hywards* (the research vehicle) and *Brass Bell* (the boost-glide vehicle), was the consolidated program Headquarters sought.

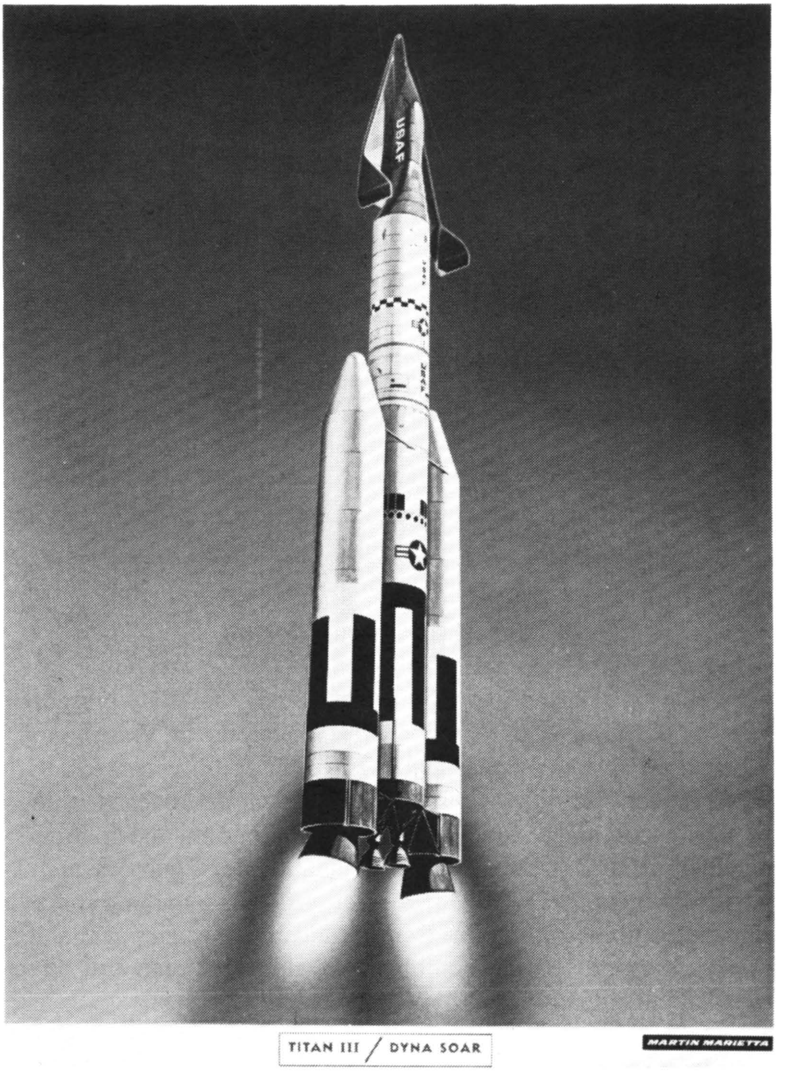

Figure 2 *Dyna-Soar* being launched by a *Titan III* booster—the definitive system concept (photo courtesy: Martin Marietta Aerospace).

Concept Definition

On 4 October 1957, the Soviet Union inaugurated the Space Age with the launch of the first artificial Earth satellite *Sputnik I*. Even while the tiny, 84-kilogram spherical moonlet was beeping across the skies, ARDC was finalizing the details of its new consolidated system development plan. The new system had a new name—*Dyna-Soar*, a concatenation of the first portions of the phases "dynamic ascent" and "soaring flight." On 10 October, the plan was completed and ready for presentation to Headquarters.

At the same time, the National Advisory Committee for Aeronautics (NACA, NASA's predecessor) became interested in concepts paralleling the Air Force's ideas. On 14 October, NACA and the Air Force met to discuss boost-glide vehicle follow-ons to the X-15 (which had been under development for nearly two years, and three of which were being built by North American Aviation in Los Angeles, California). Although NACA would play only a minor "technical advice and assistance" role in any vehicle development, the agency was interested because it would be a way to get aerodynamic data beyond the X-15's top speed of Mach 6. The Air Force included NACA's inputs into the *Dyna-Soar* plan. On 15 November, Headquarters approved the plan, following up with Development Directive 94 on 25 November, which allocated $3,000,000 of FY58 funds for *Dyna-Soar*.

On 21 December 1957, ARDC issued System Development Directive 464L, which laid out the proposed mission and general requirements for the first phase of *Dyna-Soar* and ordered the source selection process to begin.

On the first day of 1958, the Air Force distributed to thirteen aerospace contractors an RFP for *Dyna-Soar* Phase I. On 31 January, the U.S. became a contender, albeit a late starter, in the "space race" by launching the nation's first satellite, *Explorer 1*, using a modified *Redstone* booster. In March, nine contractors responded to the RFP with proposal submittals; Boeing, Convair, Douglas, Lockheed, McDonnell, Martin Company/Bell Aircraft (teamed), North American, Northrop and Republic. Their concepts, divided into "satelloid" and boost-glide categories, ranged from Lockheed's small, 2,275-kilogram "satelloid", launched by an *Atlas* ICBM, up to Republic's 7,275-kilogram missile-armed glider, which would be launched by a new, three-stage, solid-propellant booster. While the concepts differed in detail design and booster characteristics, all save one (North American's X-15 derivative) called for a delta-winged vehicle.

Within the industry, the two-man concept proposed by the Martin/Bell team was judged superior with one exception. It used a complicated and potentially failure-prone wing leading edge cooling system, consisting of a network of tubes through which coolant would circulate to absorb the heat of re-entry. Boeing's similar, but much smaller, design was simpler, having been laid out with a philosophy to keep things as simple and cheap as possible. Boeing felt an active cooling system was not needed.

Concept Refinement and System Definition

On 16 June 1958, the Air Force announced that Boeing and the Martin/Bell team were the finalists in the *Dyna-Soar* competition. Eventually, each was given $9,000,000 to perform additional concept studies and preliminary development work. The two companies worked for nearly a year refining their designs. At this time, many options were still open for the *Dyna-Soar* approach—satellite or boost-glider, manned or unmanned, research vehicle or weapon system. These basic questions continued to crop up throughout much of the program, leading to frequent re-directions and jurisdictional disputes.

While Boeing and Martin/Bell refined their concepts, ARDC re-evaluated the basic premises of their *Dyna-Soar* approach in the light of serious funding constraints, recognizing that questions were being asked at the Headquarters level about the validity and usefulness of the project. During this effort the *Dyna-Soar* System Project Office (SPO), in November 1958, came up with a new two-phase development plan. Phase I (*Dyna-Soar I*) would be a manned "experimental prototype" glider, massing between 3,180 and 5,900 kilograms, that would be used in a flight test program to explore aerodynamic characteristics, pilot performance and subsystem operation. Phase I would culminate in the first piloted orbital flight in October 1963. Concurrently with Phase I, studies for an all-up operational weapon system (Phase II), to be available in 1967, would be conducted.

Through most of 1958 and 1959, various offices within the Air Force and the Department of Defense (DoD) sparred with each other over *Dyna-Soar's* role and the program's structure. The major disagreement was whether bombardment weapon system objectives should be included—a dispute that was never resolved as long as the program existed. ARDC always held firm to the belief that *Dyna-Soar* should be the forerunner or prototype of a military manned space system but was never able to identify what specific missions such a system might perform. Air Force Headquarters, and DoD, refused to consider weapon system objectives for the program unless suitable military missions were justified. The impasse continued throughout the program. At one point, Air Force Assistant Secretary for Research and Development, R. C. Horner told General C. E. LeMay, the Air Force Vice Chief of Staff, that *Dyna-Soar* probably would be terminated "if a strong weapon system program were offered to [DoD] officials." Horner wanted only a "military research system." On 7 January 1959, in a memorandum authorizing release of $10,000,000 in on-again, off-again *Dyna-Soar* funding, Deputy Secretary of Defense Donald A. Quarles emphasized his approval was only "for a research and development project and did not constitute recognition of *Dyna-Soar* as a weapon system."

Finally, on 13 April 1959, Herbert F. York, Director of Defense for Research and Engineering, firmly and clearly stated the objectives for *Dyna-Soar I*. The program's primary goal was the non-orbital (i.e., boost-glide) exploration of hypersonic flight up to a velocity of 6,700 meters per second. The vehicle was to be manned, maneuverable and capable of pilot-controlled landings. The Air Force's pet objectives (military system testing and orbital flight) would be undertaken only if this primary goal was not adversely affected. ARDC promptly issued System Requirement 201, stating that the purpose of *Dyna-Soar* was to "determine the military potential of a boost-glide weapon system and provide research data on flight characteristics up to and including global flight."

DoD authorized expenditures of $29,500,000 for FY59 and $35,000,000 for FY60, and in effect told the Air Force to submit another program "for review," if it didn't like York's R&D objectives for the funding levels. While ARDC protested the DoD's "take it or leave it" ultimatum, York's re-direction permanently changed *Dyna-Soar* from a weapon system to an aerospace research and development (R&D) vehicle. An R&D program was easier to sell under the U.S. Space Policy set down by the Eisenhower Administration.

The Booster Issue

While the DoD and the Air Force slugged it out over the structure and objectives of *Dyna-Soar*, another battle raged on the booster front. York wanted the space plane to be launched by a booster "already in production or planned for the national ballistic missile and space programs." The only choices in these categories were Convair's SM-65 *Atlas* and Martin's SM-68 *Titan*, both ICBM's. In the revised proposals that Boeing and Martin/Bell submitted to ARDC in April 1959, Boeing specified only an orbital *Atlas-Centaur* configuration, while Martin/Bell offered a sub-orbital booster (the *Titan A*, later renamed *Titan I*) and an orbital version called *Titan C*. In June, the Air Force Source Selection Board recommended development of Boeing's *Dyna-Soar* glider, but using *Titan C* instead of *Atlas-Centaur*.

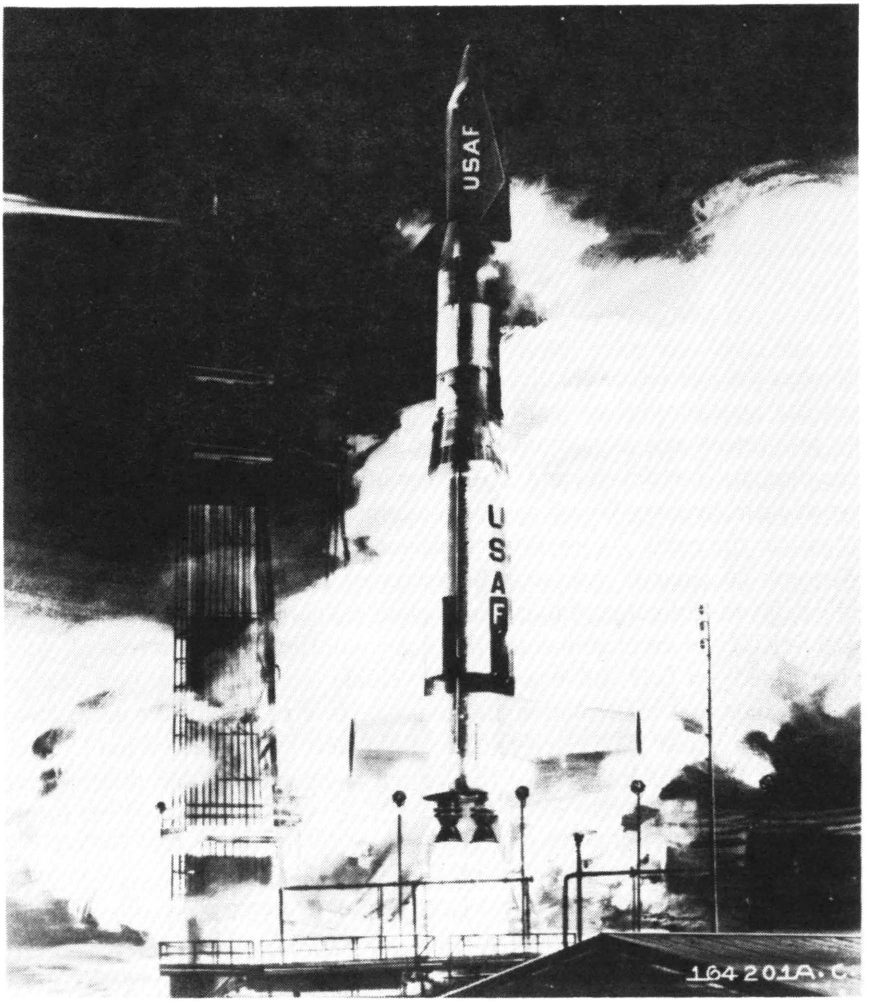

Figure 3 Boeing's *Dyna-Soar* space plane being launched by a modified Martin *Titan I* ICBM—an early sub-orbital concept that was rapidly shelved as more powerful boosters became available (photo courtesy: U.S. Air Force).

Secretary of the Air Force, J. H. Douglas disagreed. He wanted Boeing to lighten their space plane and make it compatible with *Titan A*. Herbert York threw another spanner in the works on 27 July 1959, when he requested the Secretary to investigate whether a common booster could be developed to serve as both the *Dyna-Soar* launch vehicle and the second stage of NASA's *Saturn*. The Air Force Ballistic Missiles Division (BMD) evaluated the various *Dyna-Soar* booster possibilities and, in mid-August, recommended *Titan C*. BMD considered York's "common booster" idea "impractical."

Finally, on 4 November 1959, Lieutenant General B. A. Schriever, ARDC Commander, and Lieutenant General S. E. Anderson, AMC Commander, forwarded a joint letter to Air Force Headquarters outlining their agreement on booster procurement. They proposed to "make full use of existing national booster programs," thus satisfying York's requirement, and they also planned to come up with a booster able to launch *Dyna-Soar* into orbit, thereby attaining the Air Force's objectives. On 9 November 1959, the Secretary of the Air Force announced the Boeing Airplane Company had won the *Dyna-Soar* competition and had won the systems contract. The Martin Company simultaneously was named "associate booster contractor," responsible for whatever version of *Titan* might be required. On 17 November, Headquarters directed ARDC to implement Step 1 of the new, three-step (again) program designated System 620A—a sub-orbital, manned, boost-glide, R&D space plane.

The Phase Alpha Study

Although the Air Force finally selected contractors to develop the space plane and its booster, the program did not start immediately. Projected costs were extremely high, and many prominent scientists doubted the concept would work at all. *Dyna-Soar* also faced considerable skepticism, and at times outright hostility, from high levels in the Eisenhower administration, which was never supportive of space-based weapon systems.

To palliate the critics of anything that was likely to become a space-based weapon systems, Joseph V. Charyk, Assistant Secretary of the Air Force for Research and Development, delayed obligating funds for System 620A. Instead, on 24 November 1959, he directed ARDC to re-examine all the basic configurations proposed, to determine whether the "medium L/D (lift-over-drag)" vehicle was really the best choice in terms of shape, materials and construction techniques. He also required a total re-assessment of the booster, the "step" approach and the flight test objectives. What Charyk ordered, under the name "Phase Alpha," was the virtual re-opening of the original competition. The Air Force released $1,000,000 to cover Phase Alpha work, but no further obligations could be incurred without Charyk's approval.

Phase Alpha was performed by Boeing and Martin beginning on 11 December 1959, under contract to the Air Force, and by two Air Force agencies (BMD and the Space Technology Laboratories [STL]). In early February, Colonel W. R. Grohs, Vice Commander of the Wright Air Development Division (WADD), ordered the formation of an *ad hoc* committee to evaluate the Phase Alpha Study effort. Represented on the committee were WADD, the Air Force Flight Test Center (AFFTC), AMC and NASA. To make sure all vehicle configurations were considered, the committee contracted with

AVCO Manufacturing Corporation, Bell, Chance Vought Aircraft, General Electric, Goodyear Aircraft, Lockheed and McDonnell to support the effort.

Running from January through April 1960, Phase Alpha examined the entire range of re-entry vehicle configurations, from pure ballistic shapes, through low- and medium-lift winged vehicles (some with inflatable, folding or variable-geometry lifting surfaces), to high-lift concepts. The committee concluded that a ballistic or low L/D configuration would only duplicate *Mercury*. At the other end of the spectrum, a high L/D (3.0 or greater) vehicle would provide the most useful data on re-entry performance and would have the best atmospheric maneuverability, but it would also be the riskiest and most difficult to design. The medium L/D vehicle—like Boeing's *Dyna-Soar* glider, with an L/D of about 1.5 to 2—seemed about right.

On 28 March 1960, Boeing submitted a final configuration that differed little from the original design. For the next two days, the Aerospace Vehicles Panel of the Air Force Scientific Advisory Board reviewed Phase Alpha, finally approving the findings on 25 April. The result of Phase Alpha, in addition to a stack of documents nearly four meters high, was confirmation that Boeing's design was indeed the best configuration for the job. The Panel also emphasized the importance of attaining early orbital flight, and they suggested the SPO evaluate whether Step I was really needed. With more precise planning, perhaps *Dyna-Soar* could proceed directly into the orbital Step II, complete, the Air Force hoped, with "Interim military operations." The time was not yet right for so daring an approach, however, and the SPO continued to concentrate on sub-orbital flights in its detailed planning.

On 1 April 1960, with Phase Alpha nearly over and with some assurance that *Dyna-Soar* would be funded, the SPO offered a Step I schedule. A series of piloted air-drop tests of the glider from a B-52 would begin in July 1963. Powered by a supplementary XLR-11 or AR-1 rocket engine, the vehicle eventually would reach Mach 2 during these tests. Beginning in November 1963, five unmanned sub-orbital flights were planned to demonstrate re-entry at velocities from 2,750 to 5,800 meters per second. Finally, 11 piloted sub-orbital missions were scheduled, starting in November 1964. Landing sites for these flights were: Mayaguana, in the Bahama Islands; Santa Lucia, in the Leeward Islands; and Fortaleza, Brazil. To accomplish Step I, the SPO estimated $493,600,000 would be required, spread from FY61 to FY66.

The Development Program Underway

By the summer of 1960, the Air Force had negotiated most of the major contracts with the companies that would build *Dyna-Soar*, and the program was well under way. A letter contract with Boeing for Step I was signed on 27 April, followed on 8 June by a contract with Martin for development of the booster airframe. On 27 June, the SPO contracted separately with the Aerojet General Corporation to supply first- and second-stage booster engines. On 6 December, the Minneapolis-Honeywell Regulator Company was put under contract to develop the primary guidance subsystem, and on the 16th RCA was chosen to provide the communications and data link equipment.

Although the contractors then began their development tasks in earnest (subsystem design and testing, high-temperature materials screening, wind-tunnel testing, etc.), the program itself remained unstable. Development plans continually changed, mission concepts were revised, and funding levels and schedule estimates were adjusted, promoting a sense of uncertainty and confusion, and clouding any serious Air Force attempts to clearly identify *Dyna-Soar's* place in the nation's manned spaceflight scheme.

Figure 4 Scale models showing an early *Dyna-Soar* design being air-dropped from a B-52 (photo courtesy: Boeing Aerospace).

Changes and Re-Directions

Titan I did not for long remain the booster of choice for *Dyna-Soar*. The ICBM's first stage was powered by an Aerojet General twin-chamber LR87-AJ-3 engine, with a thrust of 1,344,000 Newtons. The second stage engine was a 356,000-Newton-thrust Aerojet LR91-AJ-3. Both stages burned liquid oxygen (LOX) and highly-refined kerosene. It became apparent early-on that *Titan I's* capability for Step I flights was marginal. On 28 November 1960, C. D. Perkins, the new Assistant Secretary of the Air Force for Research and Development, requested the SPO to look into using the as-yet-unflown *Titan II* for Step I, and an all-new booster, a *Titan II* with a *Centaur*-derivative third stage, for Step II.

Titan II, which Martin began to develop in mid-1959, was slated to replace *Titan I* in America's ballistic missile arsenal. The new ICBM used storable hypergolic (i.e., self-igniting) propellants; a 50-50 blend of hydrazine and unsymmetrical dimethyl hydrazine called Aerozine 50 for the fuel and nitrogen tetroxide for the oxidizer. Both stages were more powerful than *Titan I*. The first stage produced a thrust of 1,913,000 Newtons, and the second stage was rated at 445,000 Newtons. Depending on funding levels, a switch to *Titan II* would delay *Dyna-Soar* sub-orbital flights for from two months to a year. On 21 January 1961, Air Force Headquarters granted approval for the space plane to fly on *Titan II*.

By 26 April 1961, a scant two weeks after Soviet cosmonaut Major Yuri Gagarin, in the spacecraft *Vostok*, became the first human being to orbit the Earth, the Air Force produced a further refined program definition package that elaborated on the familiar three-step approach. Step II was now divided into two sub-steps, IIA and IIB. The objectives of Step IIA were to fly *Dyna-Soar* once around the world from Cape Canaveral, Florida, to Edwards Air Force Base, California, while testing, under launch, orbital and re-entry conditions, various military subsystems such as weapon delivery equipment and reconnaissance packages. Step IIA was estimated to cost $467,800,000 and the first manned orbital flight was scheduled for April 1966. Step IIB was aimed at an "interim operational system" capable of reconnaissance, satellite interception, logistics, and bombardment missions; it was planned to be operational by October 1967. The Air Force remained silent about Step IIB costs. The new Administration of President John F. Kennedy remained silent over whether it would change President Eisenhower's dictum of no space-based weapons.

At the same time, the State Department pointed out that the Step I flights probably would not be able to land at Fortaleza, because the U.S. had not been able to renew an agreement with Brazil governing American military use of its territory. The implications of having to use alternate landing sites were severe. Important Step I research objectives would be impossible to meet, unless the space plane could land at Fortaleza. As it turned out, events were in motion that made the lack of a Brazilian landing site unimportant. The SPO was about to unveil another new plan, one that would eliminate sub-orbital flights entirely.

On 4 May 1961 (the day before Astronaut Alan Shepard's sub-orbital hop in the first manned NASA *Mercury* flight), Boeing proposed a plan for accelerating *Dyna-Soar* called Project Streamline. Boeing's approach called for elimination of the Step I sub-orbital flights, temporary use of available (i.e., already well under development) subsystems, and use of NASA's *Saturn C-1* booster for near-term orbital missions. Assuming early Air Force approval, Boeing estimated the first unmanned orbital flight could take place in April 1963, shaving about 16 months off the then-scheduled Step IIA orbital flight date of August 1964.

The SPO considered Boeing's proposal and, by the end of June, offered a slightly different twist, reverting once again to a three-step structure. The first phase, essentially Boeing's Streamline concept, was aimed at developing an orbital research vehicle. Refusing to give up its military objectives, the SPO defined the second phase to be the development and testing of military subsystems, while the third and final phase would result in an operational weapon system in space. The SPO considered three booster candidates for the Streamline phase: a modified *Saturn*, a *Titan II* with a hydrogen-oxygen second stage, and a *Titan II* augmented by solid-propellant motors. The solid-augmented *Titan* was dubbed SOLTAN (SOLid T*i*TAN), and it turned out to be the most significant and lasting legacy of the *Dyna-Soar* program. In later years, the booster originally conceived for *Dyna-Soar* served, with unprecedented reliability, as the Air Force's primary heavy expendable booster, a role it will continue to fill until well into the next century.

Booster Selection and More Mission Changes

SOLTAN initially was a strengthened, two-stage *Titan II* core with two strap-on 2.54-meter-diameter solid-propellant motors (called Stage Zero). Later, in October 1961, in a new SPO development plan, the solids were increased in diameter to 3.05 meters, and the slightly-revised SOLTAN got a new name—*Titan III*. Despite intense lobbying from sponsors of some 12 other alternate booster proposals, including *Atlas-Centaur, Saturn* and *Phoenix*, the *Titan III* continued to be the most attractive option overall, especially since the Air Force was beginning seriously to look into "high-altitude" *Dyna-Soar* satellite inspection and interception missions, for which the big booster would be well suited. Following a series of briefings by program officials to high levels of Air Force management, DoD announced, on 13 October 1961, that "*Titan III* was to be the Air Force space booster."

By the end of the summer of 1961, Boeing and the various *Dyna-Soar* subcontractors had finalized the basic glider design. From 11 September through 22, a team of Air Force officers and NASA engineers evaluated Boeing's full-scale mockup at the factory in Seattle. The mockup inspection produced no significant changes, and the way was clear for Boeing to begin constructing the first flight airframes.

On 11 December 1961, after *Dyna-Soar* officially had been under way for 18 months, Air Force Headquarters informed the SPO that the Secretary of the Air Force agreed to the first phase of the accelerated program proposal. Sub-orbital flights were dropped, and the program objective was now defined as "the early attainment of orbital flight, with the *Titan III* booster." Funding requirements were; $100,000,000 for FY62, $125,000,000 for FY63 and $420,200,000 for FY64 through FY68. The first air launch was scheduled for July 1964, the first unmanned *Dyna-Soar/Titan III* launch in February 1965, and the first manned orbital flight in August 1965. All orbital flights would end at Edwards Air Force Base in California after a single circuit of the Earth.

On 15 December 1961, NASA announced that its two-man, maneuverable *Gemini* spacecraft, an essential building block for the *Apollo* lunar landing program begun in November, would be built sole-source (i.e., without a competitive procurement) by McDonnell. On 21 December, the Deputy Chief of Staff for Systems and Logistics at Air Force Headquarters issued System Program Directive 4, and under pressure from Headquarters and DoD, the SPO clarified its position to the development contractors, stating that "no requirements existed for maneuvering in space nor for the development of military subsystems." The contractors were directed to make "only a minimum number of changes to the glider and the transition section" to make it compatible with *Titan III*. To save money, some planned wind tunnel tests were deleted, and the number of B-52 air drops was cut back from 20 to 15.

This re-direction was incorporated in an amendment to the 21 July 1960, Advanced Development Objective, deleting references to sub-orbital flights and to the development of military subsystems. *Dyna-Soar* was now returned firmly to a research vehicle only, with no further pretensions of becoming an operational military space system. Secretary of Defense, Robert S. McNamara made this quite clear in a memorandum to Secretary of the Air Force, E. M. Zuckert on 23 February 1962, three days after John Glenn's three-orbit *Mercury* flight. Endorsing the Eisenhower Administration National Space Policy, Secretary McNamara insisted that the space plane's name be changed to one more suitable for a research craft, something like a "numerical designation." The Air Force, reluctant to give up the catchy popular name, labored over this seemingly simple task. In accordance with regulations, designations such as XJN-1 and XMS-1 (for "Experimental Manned Spacecraft") were considered. On 19 June 1962, after rejecting many names offered by various Air Force agencies and the DoD, Air Force Headquarters approved the designation "X-20." Two weeks later, approval was granted for the name "*Dyna-Soar*" to be used in conjunction with "X-20."

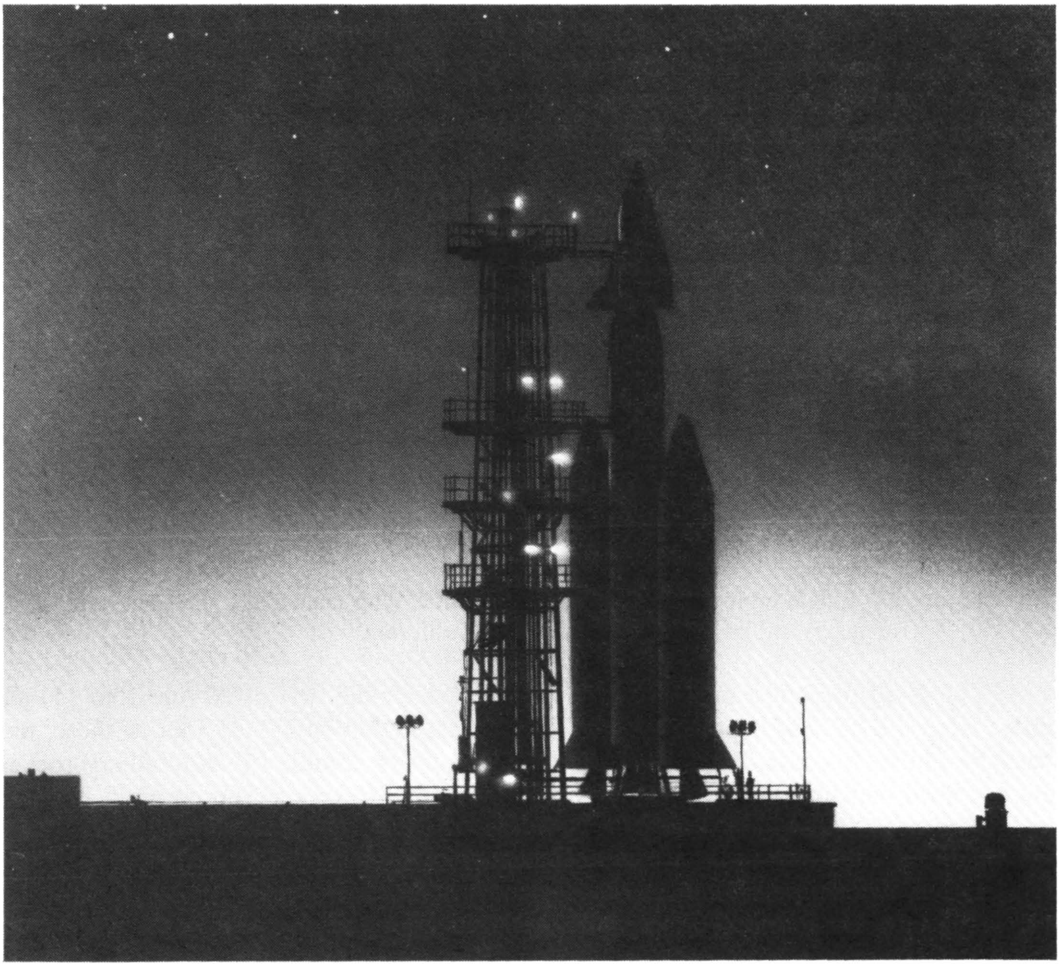

Figure 5 *Dyna-Soar* on the launch pad at Cape Canaveral atop an early finned version of the Air Force space booster workhorse *Titan III* (photo courtesy: U.S. Air Force).

Before the December 1961 re-direction, the *Dyna-Soar* SPO was responsible for developing the Step I booster. Under the new program the space plane was only one of the payloads assigned to an Air Force "standard space launch system," designated 624A, which was managed independently by the Space Systems Division (SSD). System 624A consisted of two *Titan III* launch vehicles; *Titan IIIA* was a modified *Titan II* core with a new upper stage, called "Transtage", which could place up to 3,200 kilograms into a 185-kilometer circular orbit. *Titan IIIC*, the booster scheduled to launch the X-20, was the former SOLTAN with two five-segment Stage Zero motors attached, having a liftoff thrust of about 13,344,500 Newtons. *Titan IIIC* could place up to 11,350 kilograms into low Earth orbit. For the specific X-20 trajectory its payload was limited to 9,550 kilograms.

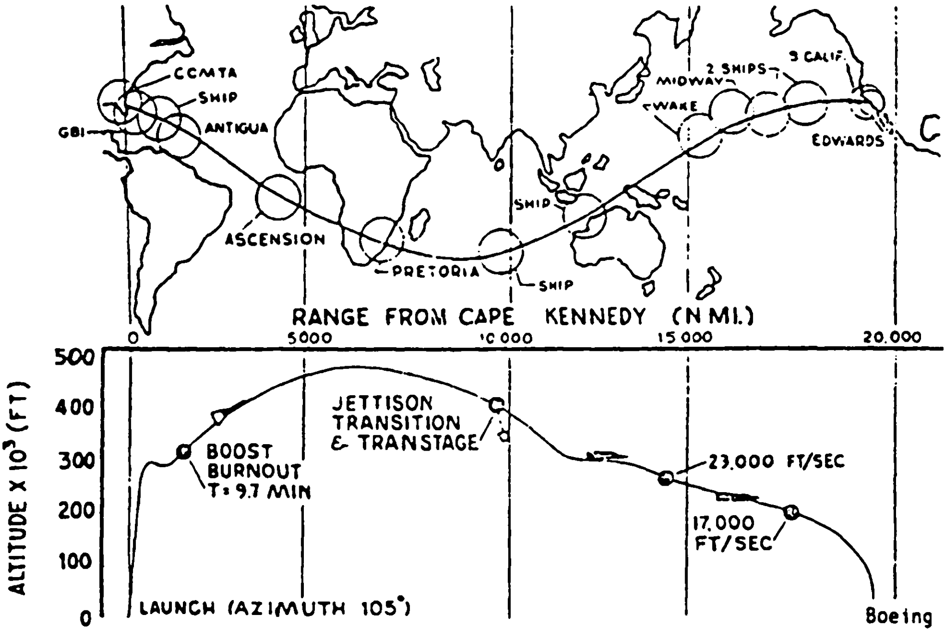

Figure 6 Single-orbit *Dyna-Soar* trajectory profile, with launch at Cape Canaveral (Kennedy) and landing at Edwards AFB, California.

The X-20 flight test program plans now called for the first of 20 (up from 15) air drops from a B-52C in September 1964 and the last in July 1965. On four of these, the X-20 would be boosted to Mach 1.4 and 21,300 meters altitude by an auxiliary rocket engine. Two unmanned orbital flights would overlap with the air drop program, in May and August 1965, to verify the booster-glider integration and to provide full-scale aerodynamic and performance data at hypersonic speeds. Finally, a series of eight piloted, single-orbit missions was scheduled to begin in November 1965 and continue through early 1967.

With the booster question settled, the SPO had another change in mind, which it introduced in a program plan revision on 14 May 1962. The new scheme involved multiple-orbit missions, beginning with the fifth or sixth manned orbital flight. This was a bigger change than it might at first seem. Throughout its development lifetime, the *Dyna-Soar* glider had always been intended for single orbits only, and its entire design was based on that premise. Upgrading it to a multiple-orbit capability would require extensive changes, especially in the areas of guidance system accuracy and subsystem reliability. The biggest impact, however, was the new requirement for a de-orbit propulsion system.

The single-orbit space plane would not need to perform a retrofire, because its flight profile was basically an around-the-world ballistic trajectory with a "free return" at the end of one circuit. After considering several options, the SPO decided to use Transtage, Martin Marietta's re-startable workhorse *Titan III* upper stage, for de-orbit propulsion. Transtage would inject *Dyna-Soar* into an extremely accurate orbit, would remain attached to the glider throughout its orbital mission, and would then retro-fire to slow the space plane for re-entry.

The funding requests for the 14 May plan were; $152,600,000 for FY63, $145,200,000 for FY64, $113,700,000 for FY65, $78,300,000 for FY66 and $17,700,000 for FY67. Added to the funds already expended, this brought the total program cost up to $682,100,000. Secretary McNamara "conditionally" approved the new plan on 13 July 1962, but he restricted the funding level for FY63 (and all later Fiscal Years) to a maximum of $135,000,000.

The first X-20 was scheduled to fly on the fourth *Titan IIIC* development shot. Because of System 624A funding and approval lags, however, SSD told the SPO on 31 August 1962, that an estimate of the launch date could not be furnished. The best SSD could offer was assurance that the first *Titan IIIC* launch would take place 29 months after "go-ahead" (expected in November), and the fourth shot, with the first X-20 payload, would follow seven months later.

The Space Plane and Its Pilots

On 20 September 1962, the Air Force revealed the names of six astronauts in training for *Dyna-Soar* at Edwards since June 1961, but who were not at the time publicly tied to the X-20 program. Five were Air Force officers; Captain Albert H. Crews, Jr. (age 33), Major Henry C. Gordon (36), Captain William J. "Pete" Knight (32), Major Russell L. Rogers (34) and Major James W. Wood (38). The sixth, then a civilian, was former Navy aviator Milton O. Thompson (36).

In conjunction with the astronaut announcement, Boeing's full-scale X-20 engineering mockup was displayed to the public for the first time at the 16th National Convention of the Air Force Association at Las Vegas, Nevada. The sleek black vehicle, 10.7 meters long and with a wingspan of 6.1 meters, was the hit of the Convention. It showed many advanced design features necessary to survive the severe launch and re-entry environments for up to four missions. The clean, highly-swept delta wing was devoid of leading- and trailing-edge high-lift devices. A spherical ceramic cap, 0.46 meters in diameter and with a melting point above 2,200 degrees C, would protect the glider's nose from the highest re-entry temperatures at the stagnation point. The radiation-cooled, welded "hot structure" would be constructed of exotic columbium alloy and coated with molybdenum. The mockup clearly showed large gaps between the simulated nickel-superalloy Rene' 41 fuselage skin panels—not sloppy construction, but deliberate, to allow the panels to thermally expand without buckling during re-entry, a technique that actually made the glider stronger as it heated up. A heat-resistant shield would cover the large, multi-pane quartz windshield and front quarter windows from launch through re-entry, and it would then be explosively jettisoned for the one-shot, dead-stick landing. (Tests had been conducted using a Navy F5D, configured with a windshield cover similar to the X-20's, to demonstrate that a pilot could safely land the glider, using small uncovered side windows only, even if the windshield cover failed to jettison).

Figure 7 Full-scale X-20 engineering mockup and the six astronauts slated to fly the space plane (photo courtesy: Boeing Aerospace).

The Final Year

Dyna-Soar's final year saw a series of Air Force attempts to keep the program alive against mounting DoD opposition to it, apparently because it lacked a defined, justifiable military mission. When 1963 began, DoD thought the alternatives were to either re-direct the program (again) to achieve military goals, or to terminate it in favor of a different approach to a manned military space system. In Secretary McNamara's view, such a system should be able to rendezvous with uncooperative targets, maneuver in orbit and during re-entry, land with precision and be re-usable with minimum refurbishment. He felt the X-20 would provide a technological basis for this system, but only in the re-entry, landing and re-usability areas. NASA's *Gemini*, with Air Force participation, would supply experience in rendezvous and orbital maneuvering.

The jurisdictional disputes that had always plagued *Dyna-Soar* continued. At meetings on 3 and 23 January, and 5 February 1963, the open conflict between SSD and the Aeronautical Systems Division (ASD), the top-level *Dyna-Soar* management office within Air Force Systems Command (AFSC), was obvious. Both agencies wanted to control the Air Force's only manned spaceflight program. This battle was the "central problem confronting the . . . program," at least internally. On 9 May, General Schriever, Commander of AFSC, emphasized that ASD was "responsible for the development of the X-20," but that SSD would supply the Test Director for all orbital flights. At the end of July, Schriever also assigned responsibility for the air-launch program and pilot training to SSD.

While the Air Force feuded internally, Secretary McNamara expanded on an interest he had originally expressed in his memo of 23 February 1962. On 18 and 19 January 1963, he ordered reviews, in quick succession, of X-20, *Gemini* and *Titan III* to determine which type of vehicle offered the more feasible approach to a military capability. On 21 January, the X-20's inertial guidance system was tested in a McDonnell NF-101B at Eglin Air Force Base, Florida, the first of 24 such tests.

The SecDef's intention, as explained to the Commanders of ASD and SSD by Major General O. J. Ritland, Air Force Deputy to the Commander for Manned Space Flight, was ultimately to define a manned military space system. The Air Force's response to his request was critically important, and Ritland assigned SSD to prepare a consolidated position. Options considered for the X-20 were; maintain the present program, re-orient it to a lower budget through FY64, accelerate the flight test program, reinstate a suborbital phase, expand the program's military objectives, and, finally, terminate the program. The recommendation, on 26 February 1963, was to continue the present program. In March, Chief of Staff, General LeMay concurred, noting that planned Air Force participation in *Gemini* was "in addition" to the X-20, not as a replacement.

Secretary McNamara was briefed on the X-20 on 11 March 1963 during a visit to the Boeing factory. He was not satisfied. He thought the Air Force had placed too much emphasis on controlled re-entry and not enough on the missions the space plane could perform in orbit. A few days later he requested further X-20/*Gemini* comparisons for four military missions; satellite inspection, satellite defense, reconnaissance and offensive operations. A joint ASD/SSD committee compiled the results of these additional studies on 10 May 1963. There was no clear-cut winner. The committee felt both vehicles could be adapted to serve as testbeds for military subsystems, but neither without modification could become a fully-operational system for any of the four missions. *Gemini* had greater orbital maneuverability and payload capacity (far more than the X-20's scant 2.1 cubic meters of capacity was available in *Gemini's* adapter module), while *Dyna-Soar* had the edge in re-entry flexibility and, unlike *Gemini*, could return test subsystems to Earth for post-flight examination and refurbishment.

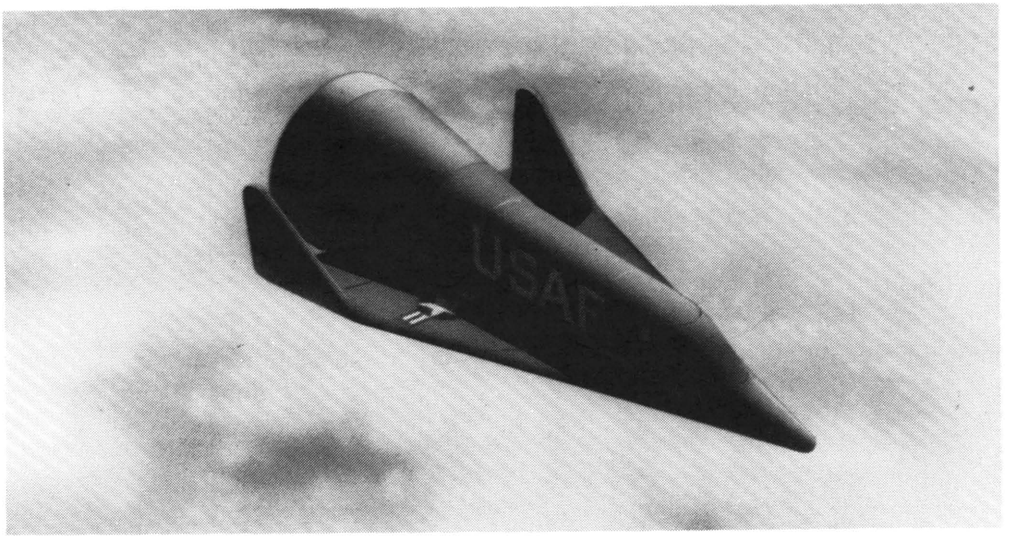

Figure 8 Artist's concept of the X-20 and its transition section in orbit, after the third stage Transtage had been jettisoned (photo courtesy: U.S. Air Force).

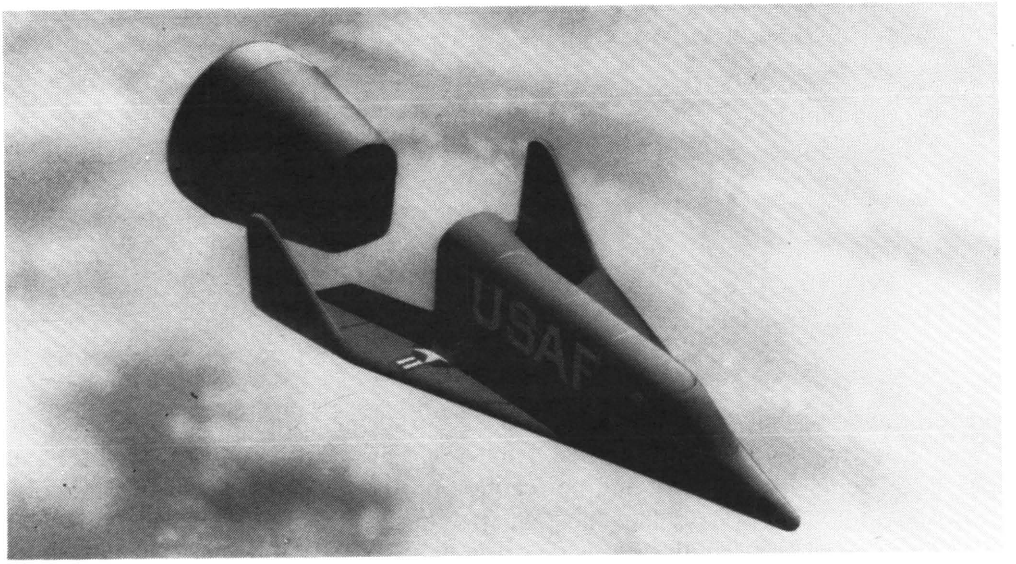

Figure 9 Just before beginning the re-entry phase of flight, the X-20's pilot would have jettisoned the transition section (photo courtesy: U.S. Air Force).

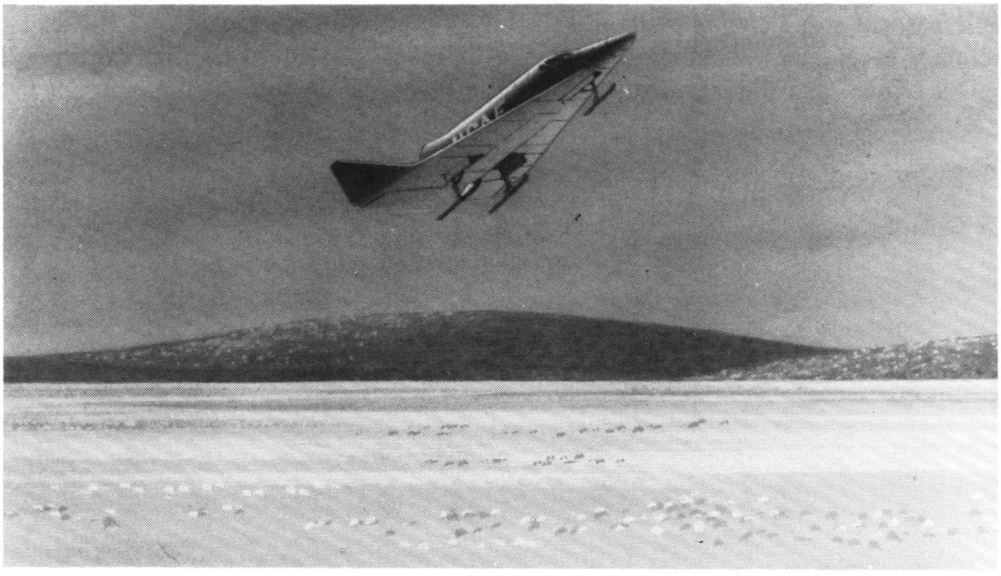

Figure 10 Following a fiery re-entry, the X-20 would have landed like a conventional aircraft on a concrete or asphalt runway or a dry lake bed (photo courtesy: U.S. Air Force).

Even though *Dyna-Soar's* future was uncertain, on 26 March 1963, the Air Force awarded Boeing a $358,076,923 contract covering modifications to B-52C serial number 53-399, conduct of the X-20 air drop tests, and one mid-1965 orbital flight from Cape Canaveral's Launch Complex 40 or 41. The first flight vehicle was being built at the time, and roll-out was scheduled for sometime in 1964.

On 22 May 1963, the ASD/SSD committee report was forwarded to Air Force Headquarters and, a few weeks later, to Secretary McNamara, along with a memorandum from Brockway McMillan, Assistant Secretary of the Air Force for Research and Development, recommending the X-20 program be "energetically continued." McMillan also suggested further study of military applications of X-20 and *Gemini*.

The X-20 SPO then looked at using the X-20 for on-orbit anti-satellite missions, proposing an X-20B model that would have an interim operational capability for satellite inspection and negation and would cost about $1,229,000,000 for a 50-flight operational program. Another study, requested by SSD in late June but not completed until mid-November, came up with an X-20X inspection vehicle, with a two-man crew, capable of 14-day missions and able to inspect foreign satellites in orbits as high as 1,850 kilometers.

By the end of June, Secretary McNamara was still studying the military potential of the X-20, and the Air Force was becoming concerned. Lieutenant General H. M. Estes, AFSC Vice Commander, instructed the SPO 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."

While the Air Force still tried to justify using the "research vehicle" X-20 for operational military missions, the space plane's future became interwoven with the nation's nascent space station plans. On 22 July Vice President Lyndon B. Johnson asked Secretary McNamara about the importance of space stations to national security. The SecDef replied that the investigation of the military role in space was important to national security, and told Vice President Johnson he hoped to have the characteristics of a manned space station defined by early 1964.

A key Air Force briefing to the President's Scientific Advisory Committee on 10 October 1963 covered possible military space missions, biomedical space experiments and ways in which *Gemini, Apollo* and X-20 fit into the overall picture. The Air Force reviewed the 10 May X-20/*Gemini* report, emphasizing use of the X-20 as a shuttle vehicle capable of rendezvous and docking. The Committee was skeptical about whether man had a definite military space utility. Committee member Lester Lees, in pre-briefing information given to the Air Force, stated that the usual arguments for manned spaceflight, such as "decisionmaking" and "flexibility," were no longer adequate, and the Air Force would have to identify more specific missions. From the Air Force perspective, the briefing went well, as at least some Committee members reversed their previous positions and now saw "a definite need" for the X-20. But the support of this Committee was not enough. *Dyna-Soar* was in big trouble.

In the meantime, on 3 September 1963, the SPO defined another revised program plan for a total cost amounting to $867,020,000 (including $339,200,000 that had already been spent). The flight dates were delayed yet again; first air drop in May 1965, first unmanned orbital flight in January 1966, first piloted orbital mission in July 1966 and first multi-orbit flight (the ninth *Titan III* shot) sometime in December 1967.

On 23 October 1963, Secretary McNamara, Harold Brown, the Secretary of Defense for Research and Engineering, and Brockway McMillan, now Under Secretary of the Air Force, were briefed by X-20 and *Titan III* officials. After the briefing, the Secretary of Defense wanted to know what the Air Force planned to do with the *Dyna-Soar* program after maneuverable re-entry had been demonstrated. He insisted he could not justify spending close to a billion dollars for a dead-end program with no ultimate purpose. Again he asked McMillan about the X-20's "possible space missions." That was the last time he asked the question.

The day after the meeting, Brown reportedly offered the Air Force a manned orbiting laboratory program in exchange for an agreement to terminate *Dyna-Soar*. General LeMay demurred. Brown's preferred concept was a four-man space station using a *Gemini* as a ferry vehicle. He recommended this approach to Secretary McNamara on 14 November, also advising canceling the X-20, which had no place in his space station schemes. The Air Force suggested three alternative X-20/space station concepts in a 4 December memorandum, which reached Secretary McNamara the next day. According to SPO estimates, the space plane could have carried four astronaut passengers, in very cramped conditions, in the pressurized equipment bay. The Air Force memo also recommended canceling NASA's *Gemini* program!

All these efforts were to no avail. On 10 December 1963, Secretary of Defense McNamara announced *Dyna-Soar's* cancellation. He gave his reasons in a news briefing. The purpose of the program, he averred, had been to demonstrate maneuverable re-entry and precision landing. The space plane was not designed to develop a capability for "space logistics" operations, could not place substantial payloads into orbit, and could not fly long-duration missions. Several hundred million dollars in additional funding would have been required to achieve "a very narrow objective."

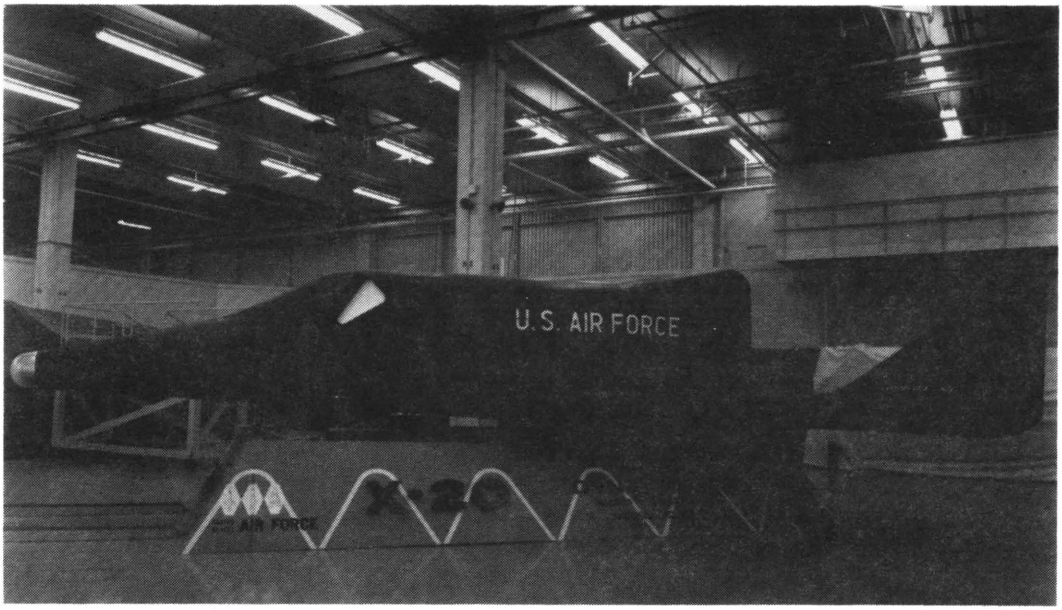

Figure 11 Boeing's X-20 *Dyna-Soar* "Piloted Research Aerospacecraft" full-scale engineering mockup at the factory in Seattle.

At the time of the X-20 cancellation, Boeing had completed about 42 percent of its tasks leading to the production of the ten X-20s on order (Air Force serial numbers 61-2374 through 61-2383) and had 6,475 people involved in the program. Minneapolis-Honeywell and RCA were both nearly 60 percent through their contracted work and had another 1,195 people working on *Dyna-Soar*. The cost of termination in human terms was devastating, especially in the Seattle, Washington area.

Ironically, the Manned Orbiting Laboratory (MOL), which DoD tossed to the Air Force in part to compensate for loss of the X-20, had no better success. MOL was unceremoniously canceled on 10 June 1969 after an expenditure of $1,400,000,000. Today, 20 years later, the Air Force still has never defined a justifiable manned military space mission, and national space policy has never acknowledged one.

Technological Legacy

Boeing's *Dyna-Soar* design philosophy called for reliance on the existing state-of-the-art as much as possible, with advanced technologies used only when absolutely required. Some new development was necessary because of the severe flight environments involved, but the X-20 was not intended to investigate advanced technologies for their own sake. This approach avoided "gold plating," often seen in modern aerospace systems. Major new technology developments were required in the areas of hypersonic aerodynamics and high-temperature materials. Less challenging design efforts were required for the on-board propulsion system, life support and avionics, landing gear and emergency systems.

Aerodynamics

The X-20's configuration was the product of over 14,000 hours of wind tunnel testing, with 1,800 hours subsonic, 3,700 hours supersonic and 8,500 hours at hypersonic speeds. Virtually all U.S. wind and shock tunnels were used at one time or another for X-20 development testing. The final vehicle design would have been able to operate over a broad range of speeds (from over 7,700 meters per second at orbit insertion to 89 meters per second at landing) and at load factors from +4 to -1g.

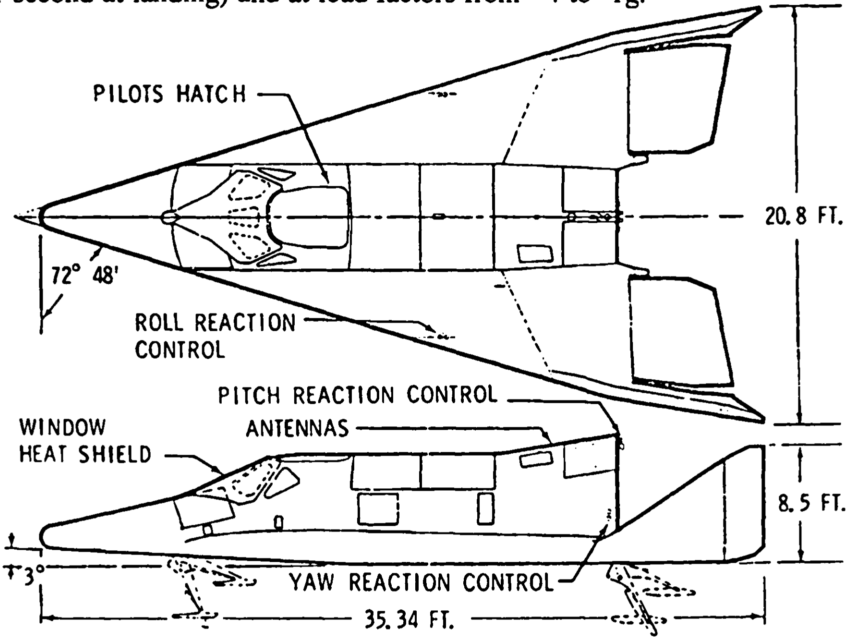

Figure 12 *Dyna-Soar* configuration layout.

The delta-winged glider would have used hydraulically-actuated trailing-edge elevons for roll and pitch control in the atmosphere, just as the shuttle Orbiter uses today. Dual-tall rudders that doubled as speed brakes were also planned. The Shuttle Orbiter uses a similar system, although its rudders are attached to a single centerline vertical stabilizer rather than to wingtip fins.

Payload capacity did not drive *Dyna-Soar's* design, because its mission was limited to the manned exploration of hypersonic and orbital flight regimes. Since the X-20 could not haul significant payloads into orbit, mission planners were forced to focus on tasks its pilot could perform, which did not involve serving as a high-tech truck driver. Lack of payload capacity made the X-20 unable to be seriously considered as a space station logistics vehicle in the program's final days. In any case, U.S. shuttle experience indicates that manned orbital operations and payload transportation functions may be incompatible with each other. As a result of the *Challenger* disaster, the current trend in the U.S. is to use unmanned, expendable boosters to launch robotic payloads whenever possible, except where on-orbit human interaction is absolutely required for satellite deployment or initialization activities. This trend could presage a return to the total separation of the two functions, as was the case in *Dyna-Soar's* day.

Materials and Thermal Protection

The X-20's passive, radiation-cooled thermal protection scheme used a variety of exotic materials, and its development advanced the state-of-the-art of superalloys, refractory alloys, ceramics, high-temperature bearings and thermal insulations, resulting in the perfection of new materials testing and manufacturing techniques. While a complete *Dyna-Soar* airframe was never built, test specimens and portions of the structure that were in assembly jigs when the program was canceled reveal the key design features.

The internal structure was a heavy truss framework made of Rene' 41, a high-nickel-content steel "superalloy" able to withstand temperatures of more than 1,000 degrees C. The truss tubes featured pinned and fixed joints in triangular elements, similar to those used in bridge construction, but not previously applied to an aerospace vehicle, to minimize thermal expansion effects. The X-20's extensive planned use of Rene' 41 stimulated the development of new welding, extruding and spinning techniques for this exotic material.

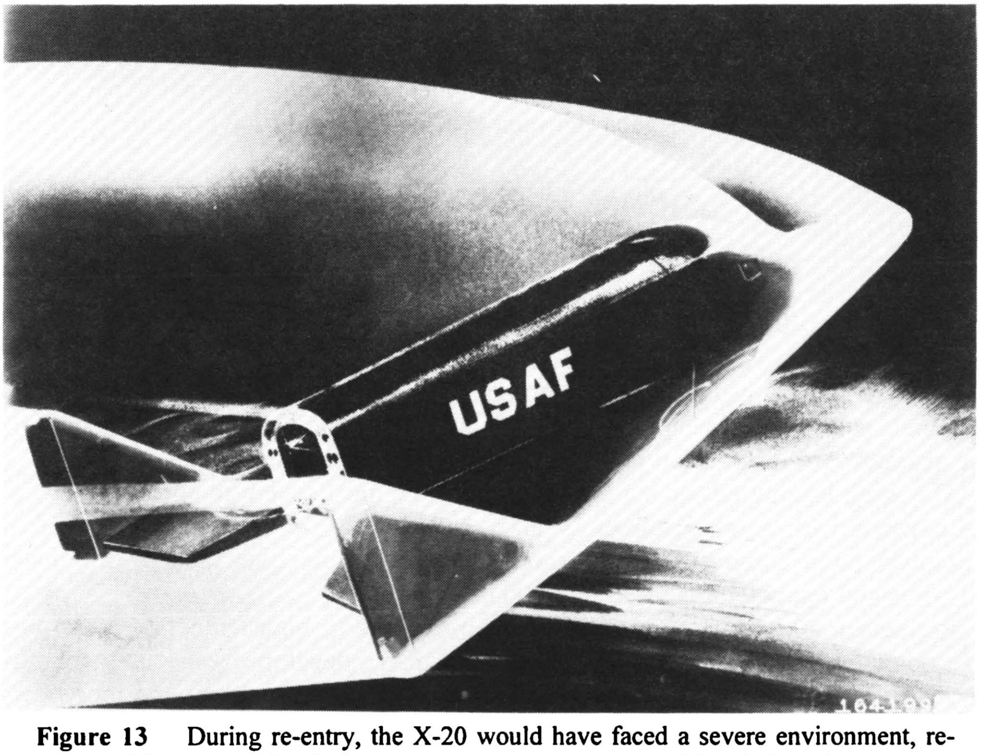

Figure 13 During re-entry, the X-20 would have faced a severe environment, requiring innovative design solutions (photo courtesy: U.S. Air Force).

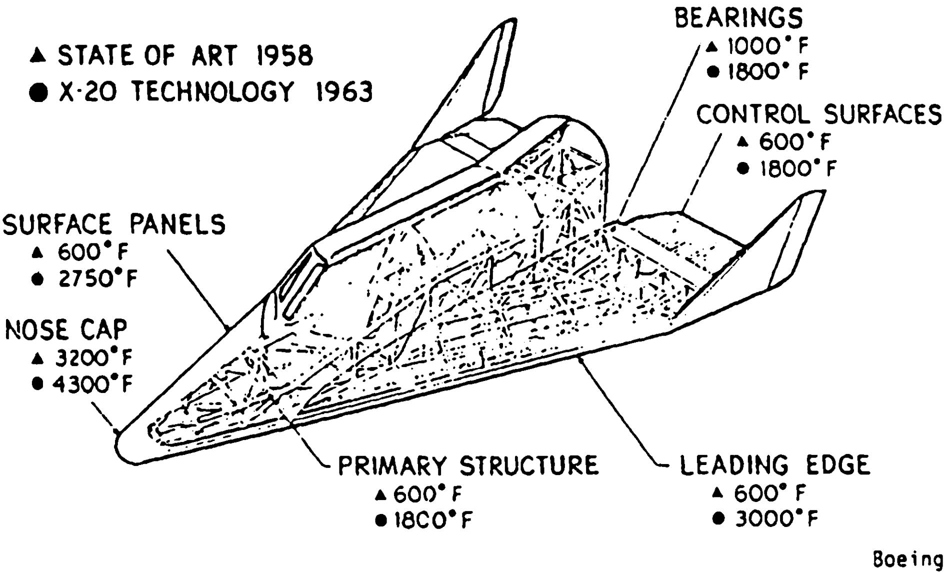

Figure 14 A graphic depiction of how *Dyna-Soar's* development advanced the state-of-the-art of high-temperature technology.

The internal framework would have been covered with an array of Rene' 41 panels, the combined assembly making up the primary load-bearing airframe structure. These panels would also provide the innermost thermal protection layer. Each panel was to be corrugated, allowing accordion-like movements to handle thermal expansion during re-entry. Relatively wide gaps between the panels would have permitted them to expand without buckling.

The Rene' 41 panels would have been covered with a silica-fiber insulation called Dyna-Quartz. Heat leakage at expansion joints, access panels, landing gear doors and control surface hingelines would have been minimized by careful gap dimension control and use of a variety of high-temperature sealing techniques.

A refractory alloy known as D-36 columbium was selected for the X-20's external skin and heat shield. This material had less strength at high temperatures than molybdenum, but it could be welded and was tolerant of temperatures over 1,500 degrees C. D-36 panels would have been attached to the insulated Rene' 41 sub-structure over most of the airframe, with expansion joints again provided between the panels.

The wing leading edges, subject to some of the most severe re-entry heating, were to be covered with another refractory alloy called TZM Molybdenum. A 50/50 titanium/molybdenum composition with small amounts of zirconium added, this material could withstand temperatures of up to 1,700 degrees C.

Refractory alloys tended to oxidize when exposed to high temperatures, so a protective coating was required. A process called DISIL, developed especially for *Dyna-Soar*, involved the application of a silicide coating on the columbium and molybdenum panels to protect them against oxidation. The space plane's outermost layer, black in color to maximize thermal emissivity, was to be a synar-silicon carbide coating. It is interesting to note that the LTV Corporation is currently developing a similar impregnated silicon carbide coating process to provide thermal protection for a National Aerospace Plane (NASP) elevon test article. *Dyna-Soar's* protective coatings would have had to be re-applied after each flight. Tests were performed to determine the damage tolerance of these materials for a variety of mission hazards, and the results indicated that most conceivable non-catastrophic damage could be repaired "in the field."

Dyna-Soar's nose would have experienced the highest re-entry temperatures, requiring use of a special ceramic nose cap. Boeing felt development of this cap represented a high risk, so two independent design efforts were carried on simultaneously. The first, at LTV Corporation, resulted in a design featuring a structural siliconized-graphite shell, protected by an outer covering of small zirconia tiles retained by zirconia pins. The tiles and pins were reinforced with platinum-rhodium wire. LTV's design was the primary candidate for operational use. Boeing's backup design was a monolithic structure of platinum-rhodium-reinforced zirconia. Hexagonal tiles cast into the outer surface allowed thermal expansion and controlled crack propagation. Both nose caps were successfully tested at temperatures up to 2,400 degrees C.

Dyna-Soar's thermal protection scheme differed from the ablative approaches used in *Mercury, Gemini* and *Apollo*. Although ablation was a simple way to resist re-entry heating, such designs were not inherently re-usable. The X-20's radiation-cooled system was a precursor to future re-usable space vehicles. The planned use of metallic materials for most of the space plane's thermal protection was an insight that unfortunately was missed when the shuttle Orbiter was designed. The Orbiter's 30,000-plus silica-based tiles, each a unique shape, provide good re-entry thermal protection, but their susceptibility to damage is very high, and their maintenance and logistics characteristics contribute significantly to the time and expense required to service an Orbiter between missions. Although re-usability and routine operations were not primary *Dyna-Soar* design drivers, its thermal protection scheme would have supported these goals as well as, or perhaps better than, the Orbiter's approach. Future re-usable spacecraft developers may have an important lesson to learn from the X-20 in designing for economical and routine re-usability.

Propulsion

The X-20 would have contained an emergency escape motor and an on-orbit attitude control system. The escape motor, a solid-propellant Thiokol XM-92, produced nearly 178,000 Newtons of thrust for about 13.4 seconds. The Air Force and Boeing's decision to provide a means for emergency escape during the boost phase was consistent with all of NASA's manned spaceflight programs and with sound engineering principles. Like all of its contemporaries, the X-20 would have ridden on top of the booster stack, which meant that, subject to aerodynamic and structural constraints, the emergency escape motor could have been used throughout the boost phase. The U.S. and Soviet shuttles, carrying their manned elements on the side of the booster stack, require more complicated, massive and fast-acting escape systems. In the case of some failures, such as the *Challenger* explosion, escape would be impossible. The X-20's escape motor would also have served as a kick motor for orbit insertion and to accelerate the space plane to supersonic speeds during the air drop program.

The attitude control system, designed by Bell Aerosystems, comprised an array of hydrogen peroxide jets similar to those used on the Bell X-1, the North American X-15 and McDonnell's *Mercury* spacecraft. Redundant pairs of jets on the wings and tail (none were planned for the nose) would have provided for pitch, yaw and roll control of the space plane.

Life Support and Avionics

A welded aluminum structure, pressurized to 0.5 atmospheres with a nitrogen/oxygen gas mixture (unlike the pure oxygen used in NASA's capsules), would have made up *Dyna-Soar's* crew compartment. A tragedy such as the *Apollo I* launch pad fire, in which astronauts Virgil Grissom, Ed White and Roger Chaffee perished in an intense blaze aggravated by the spacecraft's 100-percent-oxygen cabin environment, would have been extremely unlikely with the X-20. The crew compartment would have been thermally isolated from the outer skin by a unique water-wall heat sink consisting of a gelatinous mixture of 95 percent water and five percent Cyanogum jelling agent contained in an array of wicks. The wicks were intended to maintain a proper distribution of the jelling agent around the protected areas during all flight phases. The un-pressurized secondary power bay, located directly behind the main equipment bay, would also have been protected by the water wall.

The space plane's Minneapolis-Honeywell inertial guidance unit was derived from the system used on the General Dynamics *Centaur*. It was tested on conventional aircraft and, after *Dyna-Soar's* cancellation, in the X-15. A three-axis, self-adaptive Stability Augmentation System (SAS) was provided, and the autopilot would have used an on-board adaptive-gain computer. The SAS was designed around a piloted vehicle baseline, which was consistent with the Air Force's overall program philosophies.

An energy management display, developed by General Precision, Inc. and planned to be placed in a prominent location on the instrument panel, would have given *Dyna-Soar's* pilot a constant indication of his available landing footprint during re-entry. Energy management, the concept of balancing remaining potential energy with existing kinetic energy to control position and velocity at touchdown, is a key facet of each shuttle Orbiter re-entry, although the Orbiter is much more highly automated than the X-20 would have been. Using a side-arm controller similar to those used on the Orbiter and in high-performance aircraft, *Dyna-Soar's* pilot would have essentially flown the glider manually through re-entry to touchdown.

An integrated power generation and cooling system would have used cryogenic hydrogen and oxygen to generate electrical power, as well as to extract heat from critical on-board components. Two Sundstrand Corporation Auxiliary Power Units (APUs), each with a hydrogen-oxygen reaction chamber and a three-stage, single-disk turbine, would have driven hydraulic pumps for the flight control system and Westinghouse 12-kva electrical power generators. These generators were the first rotating electrical power sources specifically designed for use in space.

The hydrogen cooling system, developed by the Garrett Corporation, would have used hydrogen as a heat sink to absorb heat extracted from the crew compartment and equipment bay, as well as from other components in the vehicle. The system, using a glycol-water working fluid, would have featured redundant cooling loops to transfer heat from the cooled compartments, hydraulic fluid reservoirs, electrical generators and APUs to the hydrogen/glycol-water heat exchanger.

Because of its shallow re-entry flight path angle, *Dyna-Soar* would have been immersed in a plasma sheath of superheated gases for a relatively long time. A large research effort produced a design for an advanced array of antennas and communication paths to improve communications during this critical period. Super-high-frequency (SHF) antennas, massing less than 500 grams and developed using advanced materials and fabrication technologies, were proposed for four frequency ranges. A five-kilogram ultra-high-frequency (UHF) antenna, for the 400-megaHertz band, also used advanced materials and fabrication techniques. Unique rigid and flexible waveguides were also developed to support re-entry communications.

An extensive development effort was carried out to create high-temperature bearings. This effort resulted in new Stellite-19 anti-friction bearings with maximum operating temperatures of nearly 950 degrees C. A double-row array of titanium carbide anti-friction bearings was also developed with a similar temperature limit.

To support the X-20 program and general (but ill-defined) space operations requirements, a new space suit was developed by ASD and the David Clark Company. The final design, the result of extensive testing under a variety of conditions, was a suit that could be pressurized to 0.35 kilograms per square centimeter and still retain good flexibility with minimal ballooning.

For the multi-orbit missions considered late in the program, the space plans could have carried extra hydrogen, oxygen, environmental equipment and power systems in the transition section and Tran-stage. Although the single-orbit flight plan called for jettisoning these elements immediately after orbit insertion, they could have been retained until re-entry with only minor modifications.

Landing Gear

The glider's landing gear design was a retractable, hydraulically-deployed tricycle skid arrangement. Rubber tires were not considered because of the severe re-entry heat environment. The two main struts would have been fitted with articulated skis and the nose strut with an articulated shoe. The main gear skis, developed by Goodyear and resembling wire brushes, were made out of Waspalloy sheet metal with Rene' 41 wire bristles twisted over a series of longitudinal rods. The Bendix nose gear shoe was a forged Rene' 41 plate that looked something like a shallow oval kitchen dishpan.

The X-20 could have landed on concrete or asphalt runways or on dry lake beds like so many experimental aircraft before. With a very high co-efficient of friction, the gear design would have limited slide-out distances to 1.525 to 2,425 meters, thus eliminating the need for brakes. The short landing run (combined with the largely manual re-entry sequence) would have given *Dyna-Soar's* pilot great flexibility in landing site selection, unlike the shuttle Orbiter, which requires exceptionally long runways even under the best of conditions, and which depends heavily on ground-based landing aids for all but the most critical contingency landings. The Orbiters' dismal experience with tires and brakes, which typically are damaged with each landing, indicates that the X-20's landing gear design might be worth considering for future winged spacecraft.

Emergency Systems

In addition to the emergency escape rocket motor, the space plane would have been fitted with a rocket-propelled ejection seat for use during portions of the boost and landing phases (only at subsonic speeds). The *Challenger* explosion emphasizes the importance of providing a crew escape capability for all manned spacecraft. Although no such system would likely have been effective for the ill-fated *Challenger* crew, because of the nature of the accident, the Orbiter's emergency escape options, even with the current re-design that enables the crew to bail out, are very limited under virtually any contingency. The yet-unflown French *Hermes* and Japanese HOPE space planes will have better chances of escaping a launch explosion or vehicle breakup, because they will ride on top of the booster stack—as *Dyna-Soar* would have done. *Hermes* will also contain an emergency escape capsule with parachute recovery. Some current manned spacecraft designers thus seem to be returning to the *Dyna-Soar* philosophy and accepting the performance penalties imposed by carrying the extra mass of effective emergency escape systems.

A detailed study was performed to determine whether the X-20's pilot would "fly" the launch vehicle/space plane combination during the boost phase. Called Pilot in the Booster Loop (PIBOL), the study involved 100 "flights" by consultant pilots in a six-degree-of-freedom simulation. Some runs were made in the Johnsville, Pennsylvania, centrifuge to simulate acceleration and vibration environments and pressure suit mobility limitations. The results of the study showed an X-20 pilot, aided by the SAS, could successfully fly the boost trajectory. This study was significant in that it emphasized the Air Force's determination to let the pilot play a vital role in all phases of the mission, a philosophy that is not a part of the current generation of computer-controlled spacecraft. Perhaps the future will see a return to "man in the loop," when fully re-usable space vehicles may be flown into orbit as routinely as airliners fly the skies today.

Afterword

The initial planning for *Dyna-Soar* took place before the structure of the U.S. space program was defined or responsibilities for accomplishing it sorted out. In the immediate post-*Sputnik* panic that gripped the nation, there was no time to carefully lay out a logical, coherent and affordable national space program. Projects often were authorized with only cursory evaluations of their real requirements or assessments of what returns were expected from the dollars expended.

However, within the early days of the Kennedy Administration, the nation's manned spaceflight program became aligned toward the President's objective of "landing a man on the moon and returning him safely to the earth." The evolutionary *Mer-*

cury, Gemini and *Apollo* "capsule" approach offered the best chance of meeting this goal and began to consume the majority of the available space dollars. *Dyna-Soar*, which lacked an adequately justified mission, became superfluous and could not long avoid the budgetary axe.

The Air Force's space plane and NASA's capsules were two extremes of the spacecraft design spectrum, two fundamentally different ways to carry man into orbit and back to the earth. The nation could only afford to fund one approach. Before, during and after *Dyna-Soar*, the Air Force was unsuccessful in defining a requirement for a military manned spaceflight capability. Each justification the Air Force offered was rejected at the highest DoD management levels, and a sufficiently compelling reason to proceed further with *Dyna-Soar* was never identified.

Bibliography

Author's Note: Much of the material contained in this paper was obtained from three formerly classified Air Force and Boeing documents:

Geiger, Clarence J., *History of the X-20A Dyna-Soar*, AFSC Historical Publications Series 63-50-1, Historical Division, Aeronautical Systems Division, Air Force Systems Command, October 1963 (declassified 1982).

History of the Aeronautical Systems Division, July - December 1963, Volume III, "Termination of the X-20A Dyna-Soar," AFDC Historical Publications Series 64-51-III, Historical Division, Aeronautical Systems Division, Air Force Systems Command, September 1964 (declassified 1976).

"Summary of Technical Advances - X-20 Program," Report No. D2-23418, The Boeing Company, Seattle, Washington, July 1964 (declassified 1970).

Other References:

Baker, David, *The History of Manned Spaceflight*, Crown Publishers, Inc., New York, N.Y., 1981.

Boeing Company, "This is Dyna-Soar," News Release S-6826 (undated).

Bono, Philip and Kenneth Gatland, *Frontiers of Space*, Blandford Press, Ltd., London, 1969.

Caidin, Martin, *Wings Into Space*, Holt, Rinehart & Winston, Inc., New York, N.Y., 1964.

Dieffenderfer, Col. James C., "Current & Possible Future Air Force Space Programs," text of speech given at National IAS-ARS Joint Meeting, Los Angeles, California, 15 June 1961.

Gatland, Kenneth W., *Astronautics in the Sixties*, John Wiley & Sons, Inc., New York, N.Y., 1962.

Guilmartin, John F., Jr. and John Walker Mauer, "The Development of the Space Transportation System from its Earliest Beginnings through Letter Contract Finalization: A Chronology," Space Shuttle History Project, Center for the History of Leadership Institutions, October 1986 (comment draft).

Hendrickson, Walter B., Jr., *Winging Into Space*, The Bobbs-Merrill Company, Inc., New York, N.Y., 1965.

McDougall, Walter A., . . . *the Heavens and the Earth*, Basic Books, Inc., New York, N.Y., 1985.

Miller, Jay, "Ancestors of the Space Shuttle: The X-15, Dyna-Soar, X-23 and X-24 Programs," *Aerophile*, March-April 1977.

The X-Planes: X-1 to X-31, Aerofax, Inc., Arlington, Texas, 1988.

Peebles, Curtis, "The Origins of the U.S. Space Shuttle - 1," *Spaceflight*, November 1979.

Guardians: Strategic Reconnaissance Satellites, Presidio Press, Novato, California, 1987.

Smith, Marcia S., *Astronauts and Cosmonauts: Biographical and Statistical Data*, Library of Congress, 1977.

Smith, Melvyn, *Space Shuttle: U.S. Winged Spacecraft, X-15 to Orbiter*, Hayne's Publishing Group, Somerset, U.K., 1985.

Stares, Paul B., *The Militarization of Space: U.S. Policy, 1945-84*, Cornell University Press, Ithaca, N.Y., 1985.

Sunday, Terry I., "Flying Flatirons", *Wings*, August 1985.

Aviation Week & Space Technology Articles:

Alexander, George, "Unmanned X-20 Could Fly by July 1965," 19 August 1963, p. 34.

Booda, Larry, "Dyna-Soar Decision Ends Long Impasse," 1 January 1962, p. 18.

Hoffman, David H., "X-20 May Supply Orbital Space Stations," 8 October 1962, pp. 86-90.

Kolcum, Edward H., "USAF Sees X-20 Cancellation or Cutback," 25 February 1963, p. 26.

"Defense May Ease Impact of X-20 Loss," 18 March 1963, p.31.

"Dyna-Soar to Use Low-G Re-entry; Air Force Selects First Six Pilots," 24 September 1962, p. 27.

"X-20 Will Probe Piloted Lifting Re-Entry," 22 July 1963, pp. 230-240.