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Chapter 18

THE ANTECEDENTS OF THE SPACE SHUTTLE*

Richard P. Hallion†

When the Space Shuttle *Columbia* roars into orbit sometime in mid-1980, it will fulfill a dream of a half-century: The development of reusable manned spacecraft that can land like conventional airplanes. That this elusive goal is now seemingly within our grasp is because of the tireless efforts of many engineers and scientists around the world who have worked to make it reality, for the technology base that Shuttle draws upon is both multinational and interdisciplinary in scope. The Shuttle is the confluence of several broad technical streams, ranging from the rocket airplane, lifting body, and blunt-body spacecraft research, through hypersonic aerodynamics, the development of large solid and liquid-propellant rocket engines, and, finally, experience acquired in manned spacecraft programs. Technology, however, does not proceed in isolated fashion, separated from the surrounding social, cultural, and economic environment, and the Shuttle is no exception to this. The planned sophistication and capabilities originally expected of the Shuttle reflect the nature of contemporary 20th Century technology, with its buoyant self-confident optimism. The existing political and economic climate, however, forced planners to redefine its mission goals which, in turn, influenced its configuration and performance capabilities.

ORIGINS TO 1945

The origins of the Space Shuttle date to the early 20th Century. In 1903, Konstantin Eduardovich Tsiolkovskiy, a Russian school-teacher, published an article forecasting the eventual development of rocket-propelled space vehicles. Slightly later, Robert H. Goddard, the father of the liquid-fuel rocket, independently examined this same issue, also reaching a positive conclusion. Hermann Oberth undertook similar analysis with the same results about the time of the First World War. These three men, generally considered (in rocketeer G. Edward

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† Curator of Science and Technology at the National Air and Space Museum, Smithsonian Institution, Washington, D.C. and University College, University of Maryland, U.S.A. Editor's Note: This paper has since presentation in 1979 been updated after the first Shuttle flight in April 1983, and has in its new version been published in the Journal of the British Interplanetary Society, Vol. 36, pp.523-541, 1983, under the title "The Path to Space Shuttle: The Evolution of Lifting Reentry Technology".

Pendray's words) "the three great progenitors of the modern space age," were followed by a host of individuals who focused on specific problems and technical questions. One of these early spaceflight advocates, German rocket enthusiast Max Valier, believed that the manned spaceship would evolve from the all-metal airplane. For example, Valier suggested that, at first, rockets be added to conventional airplanes such as the Junkers G-23 transport. Later, designers could add more rockets and reduce the craft's wingspan. Finally, an entirely new design would be undertaken, one with six rocket engines (three in each wing) a short-span wing, and a pressurized cabin. Capable of high-speed flight in the stratosphere, this latter craft could lead to intercontinental rocket airliners. Beyond this, however, Valier generally rejected winged configurations, preferring large rockets. Tragically Valier's research ended with his death in a laboratory accident in 1930[1].

In 1925, two years after Oberth published his classic treatise *Die Rakete zu den Planetenraumen* (The Rocket into Planetary Space), and a year after Valier first gained attention with his book *Der Vorstoss in den Weltenraum* (The Advance into Space), Walter Hohmann a German civil engineer, published *Die Erreichbarkeit der Himmelskörper* (The Attainability of Celestial Bodies). Whereas previous writers had considered the problem of spaceflight in general, Hohmann examined one aspect in particular: the derivation of optimum transfer trajectories for flights from Earth to other planets. Indeed, the term "Hohmann transfer" is generally accepted world-wide. Hohmann's pioneering studies also encompassed the problem of returning to Earth. He quickly recognized the value of using the Earth's own atmosphere for retardation purposes, and, accordingly, considered the air drag forces generated by hypothetical vehicles entering the atmosphere at near-orbital velocities at altitudes ranging from 75 km to above 100 km. This further led him to consider the related problem of atmospheric heating of the returning spacecraft. Though not *per se* concerned with the *technology* of reentry, but rather with the *mechanics* of reentry, Hohmann nevertheless thought that a returning spacecraft should make use of some form of deceleration device, possibly a parachute-like aerodynamic brake, or, interestingly, variable-incidence wings. Hohmann's reentry research predated later studies of both ballistic and lifting reentry trajectories. Sadly, Hohmann himself failed to see the fruition of his efforts. His health deteriorated rapidly from overwork during the Second World War, and he died in 1945 at the age of 64[2].

The work of Oberth, Valier, and Hohmann inspired Eugen Sänger, a young Viennese engineer, to undertake his own studies of rocket and spaceflight. He quickly singled out winged spacecraft as a topic of special interest. While a doctoral candidate at the *Technische Hochschule* of Vienna in 1929, Sänger envisioned winged spacecraft boosting into Earth orbit, rendezvousing with a space station, reentering the atmosphere, and gliding down to land. By late 1938, in collaboration with Irene Bredt (whom he subsequently married), he had reached a point where he felt confident to advocate developing a spacecraft shaped like a flat iron, having low aspect wings with wedge cross-sections, and a horizontal tail of similar design with endplate vertical fins (Figure 1). Sänger and Bredt proposed launching this craft from a Mach 1.5 sled. The "Rocket Spaceplane" (as they dubbed it) could perform orbital missions with up to a four-ton payload. Its single large rocket engine would produce 100 tons thrust, with a chamber pressure of 100 atmospheres, boosting the Rocket Spaceplane into Earth orbit. The spacecraft would reenter the atmosphere in a series of skips ending in a terminal supersonic glide. With the outbreak of the Second World War, Sänger and Bredt shifted the project's emphasis from space transportation to bombardment, publishing a highly classified abbreviated report of their research in 1944[3].

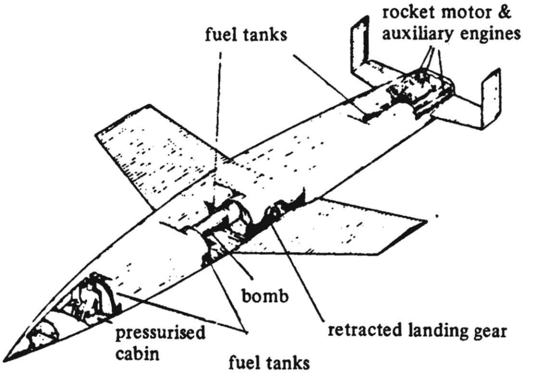

Figure 1 The Sänger-Bredt "Silbervogel" antipodal aircraft of 1944.

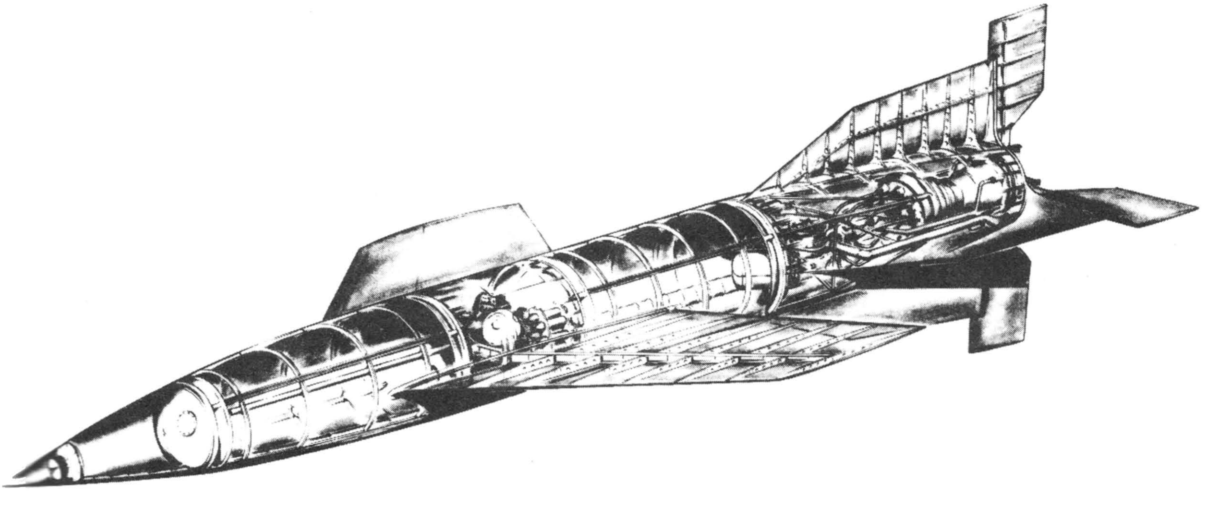

Figure 2 A lifting reentry cruise derivation of the German A-4 (V-2) missile.
A predecessor, the similar A-4b, first flew in 1945.

At the same time, members among Wernher von Braun's Peenemünde rocket team studied methods of increasing the range of ballistic missiles by adding swept-wings enabling them to glide to their targets. Under the direction of Ludwig Roth, team members developed a winged V-2 derivative, the A-4B (Figure 2). The second of two A-4B's fired in January 1945 successfully transitioned from ballistic flight to a Mach 4 glide, prior to experiencing catastrophic structural failure. (This was, incidentally, the first supersonic flight of a winged vehicle). Planners envisioned the A-4B as the forerunner of even larger winged missiles, such as the proposed winged "A-9," boosted to altitude by an "A-10" launch vehicle. The Roth team considered a piloted version of the "A-9," as well as advanced three-stage "A-11" and "A-12" boosters, the latter capable of placing 30 tons payload into Earth orbit, permitting the building of a space station. Following the collapse of Nazi Germany, these schemes greatly influenced postwar conceptions of what winged spacecraft would look like and what they could accomplish[4].

FROM A-4 TO X-15

The immediate postwar challenge facing aeronautics was the achievement of manned supersonic flight, which prompted various nations to undertake supersonic research programs. The United States responded by constructing an entire "X-series" of piloted supersonic and hypersonic flight research aircraft. As seen from a late 1950's perspective, the American program had three discernible phases: first ("Round One" in the terminology of the National Advisory Committee for Aeronautics) where the early supersonic aircraft such as the Bell XS-1 (later X-1) and Douglas D-558-2; second ("Round Two") was the hypersonic North American X-15; third ("Round Three") was the abortive Boeing-Martin X-20A *Dyna-Soar* project. The work of Sänger and Bredt, as well as indigenous American studies, directly influenced the X-15 and X-20A. While the early "Round One" research effort primarily benefited the development of conventional aircraft, it did, nevertheless, contribute to a general knowledge base that supported studies of more exotic hypersonic boost-glide vehicles, particularly in the fields of aerodynamic heating, reaction controls, high altitude physiological protection, and reusable rocket propulsion systems[5].

The discovery of the Sänger-Bredt report amidst the rubble of Nazi Germany excited great interest among Allied technical investigators. Within the United States, it focused attention on the potential of hypersonic cruise aircraft, paving the way for the X-15 and inspiring a number of orbital and suborbital hypersonic aircraft studies. For example, in 1946, Project RAND analysts endorsed studies of winged orbital spacecraft. In 1949, Hsue-shen Tsien of the California Institute of Technology proposed design of Mach 12 rocket-powered airliners, concluding that such aircraft were "not at all beyond the grasp of present day technology."[6] Walter Dornberger, the former director of Peenemünde, championed a series of Sänger-concept proposals after he joined the staff of the Bell Aircraft Corporation, as did his fellow Bell colleague, Robert J. Woods. NACA engineers L. Robert Carman and Hubert Drake of the High-Speed Flight Station advocated an orbital air-launched boost-glide aircraft (Figure 3) which, though shelved as too futuristic, was one of the earliest two-stage-to-orbit "piggyback" concepts predating the present Shuttle. The Air Force Scientific Advisory Board, the Navy's Office of Naval Research, and the Douglas Aircraft Company all sponsored similar feasibility studies. The obvious need for a hypersonic research airplane to support this work led to the NACA-Air Force-Navy X-15 program, begun in 1954.

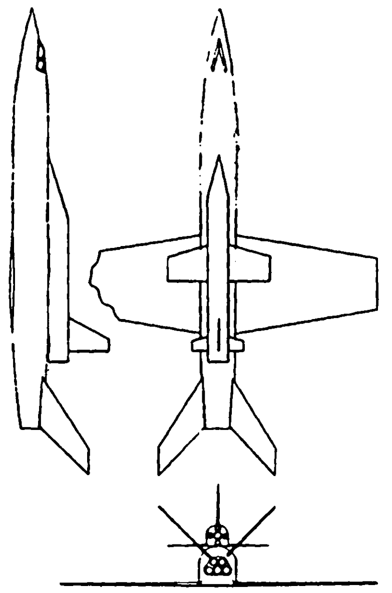

Figure 3 An early American hypersonic aircraft/orbiter proposal: the Drake-Carman composite research aircraft proposal of 1953.

The X-15 (Figure 4), which operated at an intermediate level between the purely supersonic airplane and the winged spacecraft, was the first aircraft reflecting the application of hypersonic aerodynamic theory. Its nickel alloy airframe was the first reusable super-alloy structure capable of withstanding the temperatures and thermal gradients of hypersonic reentry. North American manufactured three X-15 aircraft, and during the X-15 flights (1959-1968) they achieved speed and altitude marks of Mach 6.72 and 67+ miles (108 km), demonstrating that a piloted vehicle could boost into a near-space environment, transition from aerodynamic to reaction controls, and successfully use energy management techniques to complete hypersonic reentry followed by a glide approach to a precision landing. North American advanced a so-called "X-15B" two-man orbital spacecraft following *Sputnik*, a proposal rejected in favor of the blunt-body approach eventually used on Project Mercury. In December 1968, at the conclusion of the X-15 program; the *Deutsche Gesellschaft für Raketentechnik und Raumfahrt* awarded the X-15 research team the Eugen Sänger Medal, a fitting tribute[7].

The X-15's development occurred simultaneously with a proliferation of orbital and even interplanetary lifting reentry investigations. The Air Force studied various boost-glide military systems. In 1951-1956, Wernher von Braun, drawing on earlier Peenemünde research, postulated a variety of multi-stage launch vehicles utilizing large winged spacecraft for Earth orbital and interplanetary operations, including a proposed Mars expedition lander. The NACA forecast development of intercontinental boost-glide transports, and, in 1957, Walter Dornberger and Krafft Ehricke described one such aircraft, a two-stage air-launched rocket-propelled transcontinental transport capable of crossing the United States in 75 minutes. (Like some early Shuttle proposals, it utilized a piloted "fly-back" launch booster). This increasingly conducive climate of interest and enthusiasm for suborbital and orbital boost-gliders crystallized in the abortive X-20A *Dyna-Soar* program, the "Round Three" that followed the X-15[8].

Figure 4 North American X-15A-2.

DYNA-SOAR AND LIFTING BODIES

Dyna-Soar the most ambitious winged reentry program prior to the Space Shuttle itself, grew out of industry, Air Force, and NACA paper studies. In 1952, the Bell Aircraft Corporation had proposed developing a boost-glide piloted bomber-missile, dubbed *Bomi*, for the Air Force. With further refinement, *Bomi* evolved into an intercontinental three-stage "piggyback" reconnaissance bomber similar to later Shuttle "Triamese" configurations. At Air Force suggestion, Bell advanced a two-stage Mach 15 reconnaissance vehicle, *System 118P*, and both *Bomi* and *118P* influenced Bell's next design effort, a reconnaissance system known as *Brass Bell*. 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 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* into a single three-phase research program called *Dyna-Soar* (for *Dynamic Soaring*)[9].

Eventually, *Dyna-Soar* emerged as a radiative-cooled slender delta having a flat bottom, a rounded and tilted nose, and twin endplate vertical fins, vertically launched using a modified Titan missile as a booster. In November 1959, the Air Force selected Boeing to develop the *Dyna-Soar* glider and Martin to build its booster. The glider utilized a Rene nickel superalloy primary structure, a columbium alloy heat shield, a zirconia nose cap, and molybdenum alloy leading edges. Unfortunately, the program suffered from lack of clear definition of what its goals should be. Though, in June 1962, the Air Force designated *Dyna-Soar* as the X-20A, emphasizing its research function, some proponents attempted to transform it into an operational system by proposing utilizing it to fulfill various military and civilian space missions, including orbital supply of a space station. It was obvious, however, that the X-20A would be less than satisfactory in any of these non-research roles. *Dyna-Soar's* appeal rapidly declined over the fall of 1963. On December 10, 1963, Secretary of Defense Robert McNamara canceled *Dyna-Soar* in favor of the ill-fated Manned Orbiting Laboratory program. Privately, the Department of Defense had concluded that X-20A's reentry research objectives could be achieved more effectively and economically by launching unmanned scale model delta reentry vehicles (the concurrent ASSET program). At the time of its cancellation, the X-20A was about 2 1/2 years and an estimated $373 million away from its first flight; $410 million had been expended already. The cancellation decision is one still hotly debated to this day.* 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 generally useful exercise despite its termination[10].

In 1951, NACA engineer H. Julian Allen concluded that a blunt-body shape could furnish excellent thermal protection during reentry. Conventional blunt body shapes, however, limited reentries to ballistic or semi-ballistic flight paths. Researchers at the NACA (later NASA) Ames and Langley centers derived specially tailored blunt body shapes termed "lifting bodies" having reentry cross-range maneuvering footprints on the order of 1,500 miles (2,415 km). After studying a variety of cone, lenticular, and delta configurations, NASA selected two, the Ames M2 (a modified half-cone), and the Langley HL-10 (a modified delta), for further development. Influenced by this NASA work, the Air Force's Space Systems Division in May 1961, advocated a manned lunar land expedition, LUNEX, incorporating a three-man M2-type lifting body for the return to Earth. This plan was, of course, rejected, and NASA's lunar mission planners opted instead for a more traditional shape as ultimately selected for the Apollo Command Module. Though the two-man Gemini and the larger and more refined three-man Apollo CM had modest lifting characteristics, they remained basically ballistic vehicles[11].

The START project was one step of major significance along the road to manned lifting reentry. START (Spacecraft Technology and Advanced Reentry Tests) included launching small ASSET and PRIME test vehicles on Thor, Thor-Delta, and Atlas boosters. ASSET (Aerothermodynamic/Elastic Structural Systems

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* Editor's Note: President Dwight D. Eisenhower earlier had declared that the uses of outer space be restricted to peaceful purposes, and refused to consider for development U.S. programs that could be employed as offensive weapons. His successor, President John F. Kennedy, concurred, and the ROBO-X-20 was eventually canceled.

Environmental Tests) began in 1961; the Air Force Flight Dynamics Laboratory and McDonnell Aircraft Corporation built six ASSET delta test models which were flown from 1963 through mid-1965. START's next phase, PRIME (Precision Recovery Including Maneuvering Entry), involved launching Martin SV-5D lifting body models from Atlas boosters. Three SV-5D flights in 1966-67 confirmed that lifting body spacecraft could maneuver successfully during reentry. PRIME spawned PILOT (Piloted Lowspeed Tests), a program that led to the piloted Martin X-24A (SV-5P) rocket-propelled lifting body, to demonstrate that astronauts could control such vehicles from supersonic speeds down to unpowered landings.

NASA likewise sponsored development of glider and powered versions of its M2 and HL-10 shapes, and flew these aircraft (the NASA M2-F2, Northrop M2-F3, and Northrop HL-10) from 1963 through 1972. Together with the Air Force, NASA evaluated an advanced lifting body shape derived by the Flight Dynamics Laboratory, the X-24B, from 1972 through 1975; the flat-iron shaped X-24B was the last American rocket-powered research aircraft preceding the Shuttle. These subscale and full-scale reentry programs validated anticipated shuttle reentry heating conditions, demonstrated that maneuvering lifting reentries at near-orbital velocities were feasible, and indicated that such craft could complete unpowered descents, approaches, and landings. (As a result, NASA decided to develop the Space Shuttle without auxiliary turbojet engines for its approach to landing)[12].

PRE-SHUTTLE CONCEPTS

A perceived need for logistical spacecraft to support orbital space stations, and growing fears that the space program had inadequate provisions for emergency space rescue, provided a major impetus spurring Space Shuttle Development. Lifting reentry spacecraft appeared to offer attractive alternatives to ballistic spacecraft, such as proposed derivatives of Gemini and Apollo hardware, for space rescue and supply. In the optimistic climate of the early 1960s it seemed inconceivable that the nation would not immediately embark upon space station development after completing Apollo. This, of course, changed rapidly after July 20, 1969. All through the 1960s, NASA, primarily at its Houston and Huntsville centers, solicited a great number of industry feasibility studies examining orbiting space stations, supported by either ballistic or lifting reentry logistics vehicles. The Air Force likewise funded industry studies of lifting reentry, most notably the "Aerospaceplane" program, which started as a project to develop a recoverable space booster, though the M2 and HL-10 often served as baseline configurations.

For these investigations, many companies developed their own or used other NASA or Air Force conceptualizations. Between 1961 and 1969 a wide range of vehicles underwent evaluation, ranging from unmanned craft and 1-2 man space vehicles up to large space transporters carrying 12 or more passengers and crewmen. Companies involved in these studies included Aerojet-General, Boeing, Douglas, General Dynamics, Lockheed, McDonnell, Martin, North American (Later Rockwell), and Northrop. Many novel approaches appeared: Advanced lifting bodies, slender delta designs, craft having variable-geometry ("switchblade") wings, reentry vehicles using propulsive lift (either jet or ducted fan) for vertical landings, designs that would deploy parawings for aerodynamic descent, and, in one notable case, a North American-Rockwell concept using deployable rotors for final descent and landing. Generally, designers envisioned adapting existing launchers, such as modified Titan or Saturn 1B boosters. Some, however, considered stage, stage-and-a-half, or two-stage designs. Most two-stage designs incorporated piloted winged boosters that would cruise or glide back to the launch site after having boosted the second-stage spacecraft into orbit; these "flyback" boosters often utilized advanced rocket or ramjet propulsion[13].

Other nations actively pursued the lifting reentry concept as well. Advocates in Great Britain, France, and Germany undertook a number of Shuttle and mini-Shuttle feasibility studies during the 1960s, including the British Aircraft Corporation's MUSTARD (Figure 5) (a three-stage lifting body launch system using either a cluster or triamese approach); various French conceptions for a smaller air-launched "space taxi" by Dassault (Figure 6), Nord, Sud, SNECMA, ONERA, and ERNO working together in a cooperative program (Figure 7); a Hawker-Siddeley study for a two-stage shuttle comprised of a rocket-powered launch aircraft and a lifting body spacecraft (Figure 8); the Junkers catapult-launched two-stage *Raumtransporter*; the Nord VERAS Mach 10 technology research testbed; a Royal Aircraft Establishment study for a two-stage horizontal takeoff space transporter; and, finally, various Messerschmitt-Bölkow-Blohm investigations of two-stage lifting body and slender delta spacecraft. The range of these studies reflected obviously vigorous European interest. (In tacit recognition of this, by the end of 1970, working partnerships had developed between American and European firms engaged on Shuttle-related research. North American-Rockwell, McDonnell-Douglas, and Grumman negotiated with diverse European aerospace concerns, including the Hawker-Siddeley Group, British Aircraft Corporation, Messerschmitt-Bölkow-Blohm, ERNO, Aerospatiale, Dornier, and Dassault)[14].

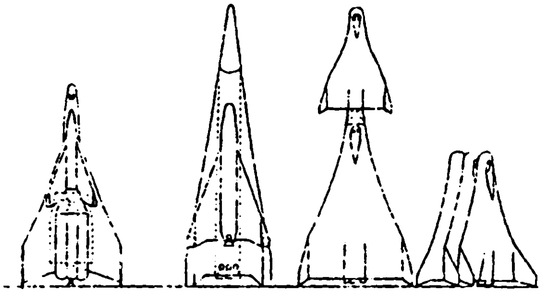

Figure 5 Alternative horizontal takeoff (HTO) and vertical takeoff (VTO) concepts for a Shuttle examined by the British Aircraft Company in the mid to late 1960s. From left: an HTO, Kerosene, M=4 airbreather + expendable and recoverable stages; an HTO rocket (sled assisted); a two stage tandem recoverable VTO rocket; "Mustard" 3-module recoverable VTO rocket. Mustard emerged as the favored concept by 1971.

In September 1966, the joint NASA Department of Defense Aeronautics and Astronautics Coordinating Board (AACB) issued a summary report on the status of reusable launch vehicle technology. The AACB report concluded that while numerous cost uncertainties and technical risks required resolution, numerous other factors encouraged reusable launch vehicle development, particularly an expected increase in manned Earth orbital flight activity. At the time, the AACB could not identify one single concept capable of satisfying both NASA and DoD's perceived future needs. Thus, the AACB examined and summarized a number of systems, including horizontal and vertical takeoff and landing vehicles, lifting bodies, winged spacecraft, single vs. multi-stage designs, air-launching, and craft blending air-breathing and rocket propulsion[15].

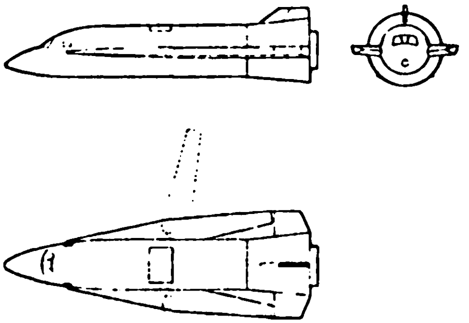

Figure 6 "Space taxi" proposal by the Centre National d'Etudes Spatiales. This craft, capable of carrying up to three or four tons into Earth orbit, would be launched from a horizontal takeoff-type winged aircraft powered by turbo-ramjet propulsion. After completing a lifting reentry, it would deploy a variable-geometry wing for its final glide to Earth. (circa 1963-1971).

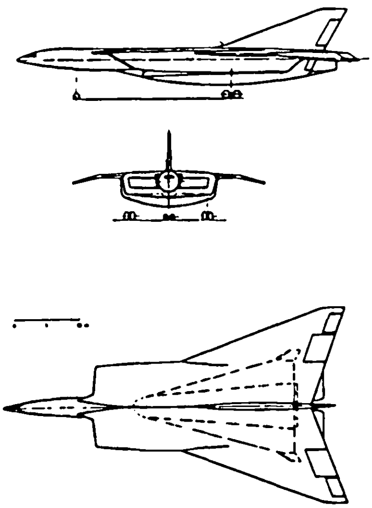

Figure 7 Joint Franco-German cooperative shuttle design study by Nord, Snecma and Entwicklungsring Nord (ERNO) for an "aerospace transporter" known as the Mistral, consisting of a winged jet-propelled launch aircraft and a lifting body orbiter nestled beneath it. Later versions of the Mistral were less elegant in appearance, and configured to launch conventional unmanned upper stages. (circa 1965-1971).

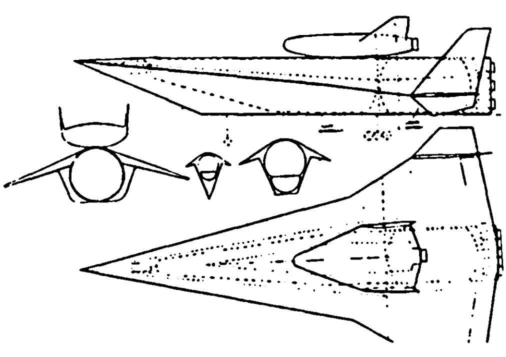

Figure 8 Two-stage fully reusable shuttle postulated by Hawker-Siddeley Aviation Limited of Great Britain, 1971.

REACHING THE FINAL SHUTTLE CONFIGURATION

Over the next three years, NASA interest in creating permanent space stations in Earth orbit supported by reusable logistical spacecraft intensified; the post-Apollo contraction of the national space program had not yet occurred. Accordingly, NASA created a Space Shuttle Task Group (SSTG) under the direction of L. E. Day to evaluate the agency's needs and system concepts. In February 1969, the agency took the first step toward what eventually emerged as the Space Shuttle with the award of four study contracts to Lockheed (Figure 9), General Dynamics, McDonnell-Douglas, and North American-Rockwell for "Integral Launch and Reentry Vehicles" (ILRV). In July 1969, the SSTG submitted its final revised report, concluding that the Shuttle should perform six major missions: space station logistical support, placement and retrieval of satellites, delivery of propulsive stages and payloads in space, propellant delivery, satellite servicing and maintenance, and short-duration orbital missions. The group preferred a fully, or near-fully, reusable system (Figures 10 and 11), and viewed the shuttle as "the keystone to the success and growth of future space flight developments for the exploration and beneficial uses of near and far space." Likewise, in its September 1969 report to the President, the Space Task Group endorsed the conclusions of the SSTG. NASA next turned to deriving an optimum design to satisfy these missions[16].

Figure 9 Lockheed "stage-and-a-half" shuttle concept, utilizing a variable geometry lifting body orbiter with flanking external fuel tanks and nosecap 1969.

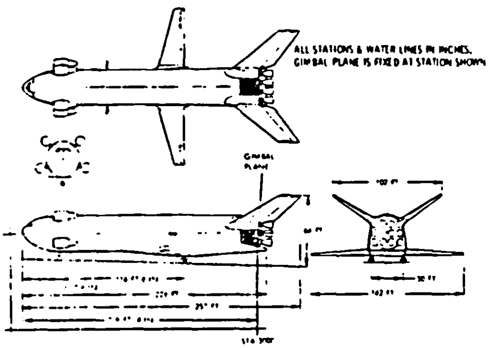

Figure 10 This 1970 booster configuration presented at a NASA MSC shuttle program technical baseline briefing illustrates the Gargantuan nature of the fully reusable studies. This booster, designed to carry low or high L/D shuttle concepts presented in the next drawing, is 257 feet long, with no less than 12 rocket engines, as well as four "pop out" turbofans for landing.

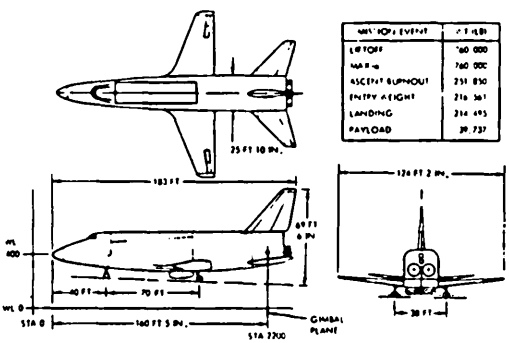

Figure 11 At the 1970 NASA MSC shuttle baseline briefing, attendees studied this refined Faget orbiter, to be airlaunched from the booster on the previous drawing. Note the small payload to orbit, as well as four landing engines deployed below the mid-fuselage. The 200 mile cross range was totally unacceptable to the Department of Defense, as was the small payload to orbit.

Such a task was not an easy one. Numerous design trade-offs had to be made, and various concepts existed for how to go about building such a craft. Opinion generally split over whether the Shuttle should use a partial or fully reusable boost system, a "flyback" booster and air-launch of the orbiter, be a straight-wing, delta, variable-geometry, or lifting body craft, be powered by existing "off the shelf" engines or have an entirely new advanced rocket propulsion system. An international symposium on the Space Shuttle arranged by NASA at the Smithsonian Institution in October 1969 addressed many of these questions. Gradually, supporters reached a general consensus: the Shuttle should be a two-stage fully reusable vehicle with a fly-back booster. It should have either a low (200 nm) 360 km or high (1,500 nm) 2,700 km reentry cross-range. It should carry a concurrently developed "space tug" to act as a logistics transport between the low-orbit Shuttle and the high-orbit space station. "Phase B" shuttle study contacts, which NASA awarded in July 1970 to McDonnell-Douglas and North American-Rockwell (later Rockwell International), supported this consensus view; as a cautionary hedge. However, NASA also awarded two "Phase A" (feasibility) studies to a Grumman-Boeing team and to Lockheed for examination of partially expendable shuttle concepts as alternatives to the more elaborate and complex Phase B baseline shuttle. As events turned out, the Phase A partially expendable studies proved wise, for the political and economic environment surrounding NASA's post-Apollo plans dictated radical revision of the anticipated Shuttle program[17].

Two major questions requiring resolution were the shuttle's aerodynamic configuration, and its booster design. The final aerodynamic configuration was largely determined by cross-range parameters and payload bay sizing requirements. Eventually, NASA and the Department of Defense opted for a reasonably high cross-range (the current Shuttle has a nominal 1,000 nm (2000 km) entry cross-range), which resulted in adoption of a delta platform. The booster configuration was inextricably bound up in arguments surrounding the size and complexity of the spacecraft (especially the question of whether or not the system should be fully reusable), as well as in the changing circumstances influencing America's space program. In 1970, NASA recognized that it could not have both the Shuttle and an orbiting space station. The Shuttle, a more modest, attainable, and attractive proposal, survived while the station did not. The next year, however, the federal government's Office of Management and Budget (OMB) indicated unwillingness to support NASA at budget levels above its 1971 annual figure of $3.2 billion, placing the Shuttle in serious jeopardy. Program costs for the fully reusable two-stage Shuttle were already rising above an estimated (and now clearly unavailable) $10 billion. Though NASA technically favored the fully reusable approach, economic considerations, supported by outside analysis, dictated otherwise. NASA had to adopt a partially expendable booster. The new unacceptable Phase B studies expanded into a "Phase B Double Prime." On January 5, 1972, President Richard M. Nixon endorsed development of the revised Shuttle, termed the Space Transportation System (STS), hailed as potentially a space-age DC-3. In March 1972, as a result of the Phase B Double Prime studies, NASA opted for a parallel-burn boost concept rather than traditional sequential staging. The Shuttle orbiter was mounted on a large fuel tank feeding the Shuttle's own engines; two solid-fuel boosters flanked the fuel tank. The orbiter itself was based upon the NASA-derived 040 Shuttle configuration. On July 26, 1972, Rockwell received a NASA go-ahead to proceed with the final design, development, and fabrication of the Space Shuttle. The go-ahead followed extensive review of the Rockwell, Grumman, McDonnell-Douglas, and Lockheed proposals by a NASA-Air Force Source Evaluation Board[18].

Without question, the NASA-Rockwell Space Shuttle represents an ambitious design. It has a body length of 122.2 ft (37.24 m), a wingspan of 78.06 ft (23.79 m), and a height of 56.67 ft (17.27 m). The external propellant tank alone measures over 154 ft (47 m) in length and is over 27 ft (8.3 m) in diameter. At launch, the Shuttle has a gross lift-off weight (GLOW) of 4.4 million lb (2 million kg), and is capable of placing up to 65,000 lb (29,484 kg) of cargo and up to seven passengers and crew into equatorial orbit 115 miles (185 km) above the Earth. Each of its two solid fuel boosters generates 2.9 million lb (13 million n) of thrust, and each of its three main engines produces a thrust of 375,000 lb (1.7 million n). Roughly the size of a Douglas DC-9 transport, the Shuttle has a cargo bay that measures 60 ft (18.28 m) in length and 15 ft (4.57 m) in diameter. Its thermal protection system consists of reinforced carbon-carbon, ceramic LI-900 material for high- and lowtemperature reusable surface insulation, and coated Nomex felt material. Rockwell began construction of the first Space Shuttle, Orbiter OV-101, on June 4, 1974, completing it in September 1976. This craft, the *Enterprise* (Figure 12), underwent approach and landing trials in 1977. The second Shuttle, Orbiter OV-102 *Columbia* is being readied for its first flight, scheduled for 1980.

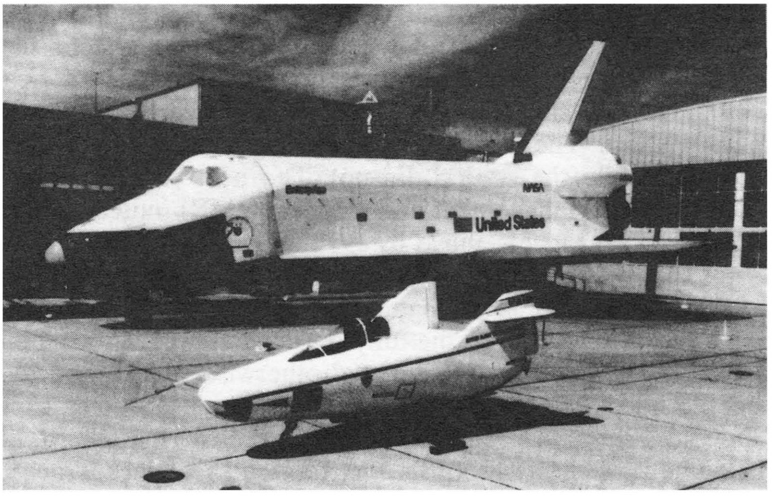

Figure 12 The M-2-F-2 lifting body in the foreground is dwarfed by the space shuttle Enterprise, from which its design and technology evolved. The two vehicles are shown at the NASA Dryden Flight Research Center at Edwards Air Force Base, California.

CONCLUSIONS

In the five decades since Eugen Sänger first examined winged orbital reentry concepts, aerospace science has advanced remarkably. Truly, humanity is on the threshold of a new era of spaceflight, for if the Shuttle fulfills its promise, it will open new vistas in international cooperation in the exploration and utilization of space[19]. That we have come this far is due in large measure to those who boldly pursued the Shuttle concept over the last half-century. Challenges remain to be faced, and problems will continue to demand solution. Such, however, is the craft of aerospace science, and we must not shrink from the task, for when the first Shuttle roars into orbit, it will represent the fulfillment of international dreams no less significant than those compelling Tsiolkovskiy, Goddard and Oberth before the dawn of the space age.

REFERENCES

1. I. Essers, *Max Valier: A Pioneer of Space Travel* (Washington, D.C. NASA, 1976), pp. 81, 92-97, 130-135, 248.

2. Werner Schulz, "Walter Hohmann's Contributions Towards Space Flight: An Appreciation on the Occasion of the Centenary of his Birthday," XXXth Congress, International Astronautical Federation, Munich, FRG, Sept. 21, 1979.*

* **Editors Note:** Published in this Volume.

3. Eugen Sänger and Irene Bredt, *Über einen Raketenantrieb für Fernbomber*, Deutsche Luftfahrtforschung UM 3538, (Ainring: DFS, Aug. 1944), translated by the Naval Technical Information Branch, Bureau of Aeronautics, as Translation CGD-32, *A Rocket Drive for Long-Range Bombers* (1952). See also Eugen Sänger, *Raketenflugtechnik* (Munich: Verlag von R. Oldenbourg, 1933), translated by the National Aeronautics and Space Administration as NASA TT F-223, *Rocket Flight Engineering* (Washington, D.C.: NASA, 1965); Eugen Sänger, "Neure Ergebnisse der Raketenflugtechnik," *Flug: Zeitschrift für das gesamte Gebiet der Luftfahrt* (December 1934), pp.10-22; Irene Sänger-Bredt, "The Silver Bird Story: A Memoir," in R. Cargill Hall ed., *Essays on the History of Rocketry and Astronautics: Proceedings of the Third Through the Sixth History Symposia of the International Academy of Astronautics*, v. I (Washington, D.C.: NASA, 1977), pp.195-228 (reprinted as Vol 7-I, *AAS History Series*, 1986).

4. Wernher von Braun, "German Rocketry," in Arthur C. Clarke, ed., *The Coming of the Space Age* (New York: Meredith Press, 1967), pp.54-55; Frederick I. Ordway III and Mitchell R. Sharpe, *The Rocket Team* (New York: Thomas Y. Crowell Publishers, 1979), pp.54-57; Walter Dornberger, *V-2* (New York: The Viking Press, 1958), pp.250-251, Rowland F. Pocock, *German Guided Missiles of the Second World War* (New York: Arco Publishing Company, 1-67), pp.98-99.

5. Walter C. Williams and Hubert M. Drake, "The Research Airplane: Past, Present, and Future," *Aeronautical Engineering Review* (Jan. 1958), pp.36-41; Kenneth S. Kleinknecht, "The Rocket Research Airplanes," in Eugene M. Emme, ed., *The History of Rocket Technology: Essays on Research, Development, and Utility* (Detroit: Wayne State University Press, 1964), pp.189-211; Richard P. Hallion, "American Rocket Aircraft: Precursors to Manned Flight Beyond the Atmosphere," in K. R. Lattu, ed., *History of Rocketry and Astronautics*, *AAS History Series*, Vol. 8 (San Diego, CA: AAS, 1989), pp.283-313 (paper presented at the XXVth Congress, International Astronautical Federation, Amsterdam, The Netherlands, Oct. 4, 1974); Richard P. Hallion, *Supersonic Flight: Breaking the Sound Barrier and Beyond* (New York: Macmillan, 1972).

6. Hsue-shen Tsien, "Instruction and Research at the Daniel and Florence Guggenheim Jet Propulsion Center," *Journal of the American Rocket Society* (June 1950), pp.51-64.

7. Meeting minutes, NACA Committee on Aerodynamics, Oct. 4, 1951; Jan. 30, 1952; June 24, 1952; Staff report, "Conception and Research Background on the X-15 Project," NASA Langley Research Center, June 1962; Staff report (draft), "History of NACA-Proposed High-Mach Number, High-Altitude Research Airplane," NASA Langley Research Center, n.d.; Hubert M. Drake and L. Robert Carman, "A Suggestion of Means for Flight Research at Hypersonic Velocities and High Altitudes," (NACA High-Speed Flight Research Station, n.d.); Hubert M. Drake and L. Robert Carman, "Suggested Program for High-Speed, High-Altitude Flight Research," (NACA HSFRS, Aug. 1953); Douglas Aircraft Company, Summary Report for Contract NONR 1266(00), "High Altitude and High Speed Study," (El Segundo: May 28, 1954); letter Edward H. Heinemann to author, Feb. 10, 1972; Thomas A. Sturm, *The USAF Scientific Advisory Board: Its First Twenty Years, 1944-1964* (Washington, D.C.: USAF Historical Division Liaison Office, Feb. 1, 1967), p.59; John V. Becker, "The X-15 Project," *Astronautics & Aeronautics* (Feb. 1964), pp.52-61; George W. Hoover, "U.S. Navy Developments Leading to Space Flight: A Memoir," (New York: American Institute of Aeronautics and Astronautics, 1970); NACA Research Airplane Projects Panel meeting minutes, Feb. 4-5, 1954; Interview with John H. Becker, Nov. 12, 1971; Robert S. Houston, *Development of the X-15 Research Aircraft, 1954-1959*, v. III of *History of Wright Air Development Center, 1958* (Wright-Patterson AFB: Office of Information Services, Wright Air Development Center, June 1959); John V. Becker, "Principal Technology Contribution of the X-15 Program," (NASA Langley Research Center, Oct. 8, 1968); Wendell H. Stillwell, *X-15 Research Results* (Washington, D.C.: NASA, 1965); Joseph Weil, NASA TN D-1278, *Review of the X-15 Program* (Washington, D.C.: NASA, June 1962); James E. Love, "X-15: Past and Future," paper presented to the Fort Wayne Section, Society of Automotive Engineers, Dec. 9, 1964; Walter C. Williams, "The Role of the Pilot in the Mercury and X-15 Flights," Proceedings of the 14th AGARD General Assembly, NATO, Sept. 16-17, 1964, Portugal; John V. Becker, "The X-15 Program in Retrospect," *Raumfahrtforschung* (March-April 1969), pp.45-53; Richard P. Hallion, "X-15: Highest and Fastest of Them All," *Flight International* Dec. 23, 1978), pp.2256-2257, 2258, 2262.

8. C. E. Brown, *et al*, "A Study of the Problems Relating to High-Speed High-Altitude Flight,: (NACA Langley Laboratory, June 25, 1935); Willy Ley and Chesley Bonestell, *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; Wernher von Braun, *The Mars Project* (Urbana: University of Illinois Press, 1953); Willy Ley and Wernher von Braun, *The Exploration of Mars* (New York: The Viking Press, 1956); Willy Ley, *Rocket, Missiles and Men in Space* (New York: The Viking Press, 1968), pp.449-450; E. P. Smith, "Space Shuttle in Perspective: History in the Making," paper presented at the 11th Annual Meeting of the American Institute of Aeronautics and Astronautics, Washington, D.C., Feb. 24-26, 1975.

9. Clarence J. Geiger, *History of the X-20A Dyna-Soar*, v. I (Historical Division, Aeronautical Systems Division, Air Force Systems Command: Oct. 1963); Boeing X-20A Dyna-Soar release S-7348, March 4, 1963; 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); Lloyd 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; 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 History Symposia of the International Academy of Astronautics*, v. II (Washington, D.C.: NASA, 1977); pp.463-465 (reprinted as Vol. 7-II, *AAS History Series*, 1986).

10. Clarence J. Geiger, *Termination of the X-20A Dyna-Soar*, v.III (Historical Division, Aeronautical Systems Division, Air Force Systems Command: Sept. 1964); Boeing, "Summary of Technical Advances: X-20 Program," (The Boeing Company, Aerospace Division, D2-23418: July 1964); Memo for Secretary of Defense from Robert C. Seamans, Jr., and Harold Brown, signed Jan. 29-31, 1964; conversation with John V. Becker, Nov. 12, 1971; Robert F. Futrell, *Ideas, Concepts, Doctrine: A History of Basic Thinking in the United States Air Force, 1907-1964* (Maxwell AFB: USAF Air University, 1974), pp.431-437.

11. Support Systems Plans Division, *Lunar Expedition Plan: LUNEX* (Hq. Space Systems Division, AFSC, May 1961); Edwin P. Hartman, *Adventures in Research: A History of the Ames Research Center, 1940-1965* (Washington, D.C.: NASA, 1970), pp.215-218, 226-270, 294-298, 359-363, 451-452; C. A. Syvertson, "Aircraft Without Wings," *Science Journal* (Dec. 1968), pp.46-50; "Lifting Bodies: Coming In on a Vanishing Wing," *Northrop Technical Digest* (June 1967), pp.1-17; E. P. Smith, "Space Shuttle in Perspective"; conversation with Clarence A. Syvertson, March 7, 1979; Courtney G. Brook, James M. Grimwood, and Lloyd S. Swenson, *Chariots for Apollo: A History of Manned Lunar Spacecraft* (Washington, D.C.: NASA, 1979), p.62.

12. U.S. House Committee on Science and Astronautics, *1967 NASA Authorization*, Pt. 2, 89th Congress, 2nd session, February-March 1966, pp.1073-1077;________., *1968 NASA Authorization*, Pt. 2, 90th Congress, 1st session, April 1967. pp.1011-1012; "McDonnell Corp. Making Space Research Craft," St. Louis *Post-Despatch*, Jan. 6, 1963; Frank G. McGuire, "First ASSET Launches Due in Summer," *Missiles and Rockets* (Jan. 14, 1963), p.18; "Space Glider Lost at Sea After Suborbital Flight,: *The Washington Post*, Feb. 24, 1965; USAF AFSC news release 31.65; "START and SV-5 Shuttle Get Go-Ahead," *Space Daily*, March 4, 1965; "Decision on AF Manned Space Shuttle Nears," *Space Daily*, Sept. 20, 1965; William J. Normyle, "Manned Flight Tests to Seek Lifting-Body Technology," *Aviation Week & Space Technology*, (May 16, 1966), pp.64-75; "PRIME SV-5D-III Maneuvers and Recovered," *Space Daily*, April 21, 1967; James J. Haggerty, "USAF Finishes PRIME Project," *The Journal of the Armed Forces* (June 3, 1967), p.7; Syvertson, "Aircraft Without Wings"; Northrop, "Lifting Bodies: Coming in on a Vanishing Wing"; U.S. Senate, Committee on Aeronautical and Space Sciences, *1964 NASA Authorization*, Pt. 1, 88th Congress, 1st session, April 1963, pp.40, 608-634, Pt. 2, 88th Congress, 1st session, June 1963, pp.919-920; NASA Flight Research Center *X-Press*, various issues 1966-1967; conversations with Paul Bikle, Victor Horton, Richard Klein, R. Dale Reed, and Milton Thompson of the NASA Dryden Flight Research Center; ltr., Bisplinghoff to NASA center directors, Oct. 28, 1964; ltr., Eggers to Bikle, Aug. 18, 1964; M2-F1, M2-F2/M2-F3, HL-10, and X-24A flight reports, in the files of the NASA Dryden Flight Research Center; Richard P. Hallion, "Saga of the Rocket Ships: The Lifting Bodies," *Air Enthusiast*, (November 1978), *passim*; Johnny G. Armstrong, *Flight Planning and Conduct of the X-24B Research Aircraft Flight Test*

Program, AFFTC-TR-76-11 (Edwards AFB: Air Force Flight Test Center, 1977), *passim*; John A. Manke and Michael V. Love, "X-24B Flight Test Program," paper presented to the annual meeting of The Society of Experimental Test Pilots, Los Angeles, Calif., Sept. 26, 1975; conversations with John Manke and Jack Kolf; Michael L. Yaffee, "X-24B Lifting Body Nearing Completion," *Aviation Week & Space Technology* (Sept. 4, 1972), pp.77-79.

13. A comprehensive collection of these studies has been assembled at the NASA Johnson Space Center's Historical Office by Mr. James M. Grimwood. The following partial listing consists of abbreviated titles arranged in chronological order: Lockheed-NASA feasibility study of 10-ton orbital carrier (Aug. 16, 1962); Boeing lifting reentry logistics spacecraft (May 1963); Boeing Model 920-26 spacecraft (Feb. 3, 1964); Lockheed-AF preliminary study of two high L/D reentry vehicles (Sept. 10, 1964); McDonnell mission requirements of lifting systems (March 24, 1965); Boeing operational aspects of lifting systems (Aug. 1965); McDonnell mission requirements of lifting systems--final oral briefing (Aug. 18, 1965); Douglas parametric study of logistics entry vehicles (Sept. 1965); Martin-Marietta study of lifting bodies (May 1967); Convair studies of turbofan v.g. spacecraft (July 6, 1967); Convair study of propulsive lift descent and landing (Aug. 15, 1967); Convair v.g. spacecraft studies (July 12, 1968); North American-Rockwell deployable rotor reentry vehicles (Dec. 1968); see also "Aerospaceplane May Be Two-Stage Vehicle," *Aviation Week & Space Technology* (July 22, 1963), pp.245-249; NASA-DoD AACB, *Report of the Ad Hoc Subpanel on Reusable Launch Vehicle Technology* (NASA Hq. Sept. 14, 1966).

14. See, for example, the contributions of C. Bigot, Marcel Stoll, Mme. Vinas-Espin, C. Reinhold, R. F. Creasey and T. Smith, P. J. McKenzie, F. Mysliwetz, H. Tolle, G. Leroy, and R. Marquet in *Selection of Papers Presented at the Space Shuttle Symposium, Smithsonian Museum of Natural History, Washington, D.C. October 16, 19, 1969* (Washington, D.C.: NASA, 1969); Irene Sänger-Bredt, "The Silver Bird Story," Vol. 7-I, *AAS History Series*, pp. 224-225; ltr., Dale D. Myers to Robert R. Gilruth, Dec. 9, 1970.

15. NASA-DoD AACB, *Report of the Ad Hoc Subpanel on Reusable Launch Vehicle Technology, passim.*

16. NASA Office of Manned Space Flight, *NASA's Manned Space Flight Program* (Washington, D.C.: NASA, April 29, 1969), pp.233-234; Space Shuttle Task Group, *NASA Space Shuttle Summary Report* (Washington, D.C.: NASA, rev. ed., July 31, 1969); John M. Logsdon, "The Space Shuttle Decision: Technology and Political Choice," *Journal of Contemporary Business*, VII, no. 3 (1978), pp.13-30; J. C. D. Blaine, *The End of an Era in Space Exploration* (San Diego: American Astronautical Society, 1976), pp.165-169.

17. Logsdon, "The Space Shuttle Decision"; NASA MSFC release 70-102, May 26, 1970; ltr., Meyers to Gilruth, June 30, 1970; Space Shuttle Phase B Study Control Document NAS 9-10960, June 1970; NASA, "Statement of Work for Space Transportation System," Sept. 2, 1969; conversation with Max Faget, March 22, 1979; Hans Mark, "The Impact of Our Enterprise in Space," *Technology in Society*, I, no. 1 (1979), pp.43-53. The various NASA and industry-derived ILRV studies, together with internal and external commentaries and correspondence, are on file at the History Office, NASA Johnson Space Center.

18. Logsdon, "The Space Shuttle Decision"; conversation with James C. Fletcher, July 20, 1979; Smith, "Space Shuttle in Perspective"; James C. Fletcher, George M. Low, and Richard C. McCurdy, "Selection of Contractor for Space Shuttle Program," (Sept. 1972); Harry A. Scott, "Space Shuttle: A Case Study in Design," *Astronautics & Aeronautics* (June 1979), pp.54-58; Rockwell International, *Space Shuttle Transportation System* (Downey, Calif.: Rockwell, 1977); NASA "Space Shuttle" news release, Feb. 8, 1972.

19. For example, see Robert Salkeld, Donald W. Patterson, and Jerry Grey, *Space Transportation Systems*, v. I of *AIAA Aerospace Assessment Series* (New York: AIAA, 1978); Jerry Grey, *Enterprise* (New York: William Morrow and Company, Inc., 1979); Marshall H. Kaplan, *Space Shuttle: America's Wings to the Future* (Fallbrook, Calif.: Aero Publishers, 1979); AAS, *Space*

Shuttles and Interplanetary Missions, v. XXVIII of *Advances in the Astronautical Sciences* (San Diego: American Astronautical Society, 1970); AAS, *Space Shuttle Mission of the 80's*, v. XXXII of *Advances in the Astronautical Sciences* (San Diego: American Astronautical Society, 1976); Gerard K. O'Neill, *The High Frontier: Human Colonies in Space* (New York: William Morrow and Company, Inc., 1977).