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Problems Faced by Early Space Transportation Planners

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ABSTRACT

The problems faced by early planners of U.S. space boosters up to Saturn are described beginning with early space flight proposals, extending through the golden age of rocket technology during the 1950s, and following the reactions to Soviet space accomplishments. The problems--a mixture of sorting out futuristic conceptions, settling differences over what was technically feasible, and gaining political and public acceptance--could have their counterparts today.

INTRODUCTION

The solutions to problems of space transportation depend now, as in the past, on a melding of what is desired with what is technically feasible and what is economically and politically acceptable. In this paper, past problems and some solutions in space transportation will be discussed by recounting some selected activities up through the 1950s. (1)

That space transportation is desirable and feasible has been proclaimed for a long time. Indeed, it is inseparable from any manned space flight proposal, of which there were many prior to World War II ranging from the frivolous to scientific analyses. The first of the scientific was a paper by Tsiolkovskiy who in 1903 developed the theory of rocket flight and described a manned rocket using liquid hydrogen-oxygen. He was followed by Goddard, who combined theory with experiment; by Oberth, who expanded rocket theory and suggested innovations used today; and by Valier, who was prolific in ideas for peaceful space exploration. In the late 1920s and early 1930s, Valier and Tsiolkovskiy independently began developing the thesis that the way to the stars was the gradual increase in the capability of the airplane from atmospheric to interplanetary flight. There was, however,

little attention given to the return trip until the papers of Sanger and Bredt who discussed hypervelocity winged vehicles that returned to earth by skip-glide paths. (2)

SPACE ACTIVITIES AND ATTITUDES, 1945-49

Although Goddard flew the first liquid propellant rocket in 1926, the practicality and potential of liquid rockets was not convincingly demonstrated until the mass produced German war weapon, the A-4. The "A" series plan extended to A-9, a winged vehicle for increasing range by a skip-glide path. In 1945, the A-4's chief engineer, Wernher von Braun, excited the imagination of many with his views on future space possibilities including multi-stage piloted vehicles orbiting the earth. (3) He was the first to speak of practical space flight from a position of recognized and impressive rocket accomplishments but even so, acceptance was limited. The future of rockets beyond A-4 capability received a mixed reception among U.S. Government officials in 1945-46. At one extreme was the optimism of forward-looking Gen. H.H. Arnold, chief of the Army Air Forces who, with the advice of a group of aeronautical experts headed by Theodore von Karman, forecast that strategic bombers would eventually be replaced by long-range ballistic missiles; at the other extreme was the pessimism of conservative, highly respected Dr. Vannevar Bush, head of the Office of Scientific Research and Development, and Dr. Jerome Hunsaker, chairman of the National Advisory Committee for Aeronautics (NACA), both of whom saw long-range rocket missiles as (4) impossible for many years to come, at best. One of the chief reasons for such pessimism was the values of the exhaust velocity and the ratio of full to empty mass of the A-4. Anyone familiar with the Tsiolkovskiy

equation which relates these to vehicle velocity could see that appreciable improvements in both would be necessary to increase its range, and these improvements appeared hard to achieve. Space enthusiasts might brush such problems aside but the key people controlling government purse strings remained unconvinced. In this kind of environment, rocket research and development proceeded at a relatively slow pace. The Army showed the most initiative in ballistic missiles and organized a strong team headed by von Braun. Mid-level Navy men started a project for a satellite to be boosted into orbit by a single stage using hydrogen-oxygen but it never received strong support at top Navy levels and faded by 1948. (5) Despite the optimism of Arnold, the Air Force blew hot and cold on rocket missiles and satellites. Analyses of satellites and boosters were conducted by Douglas-Rand in 1945-46 for the Air Force and contracts (the MX series) were started for missiles in three ranges up to 8000 kilometers. By the end of 1946, however, international and national events resulted in the Air Force switching emphasis from rocket to air-breathing propulsion, and this was not reversed until the early 1950s.

SIGNIFICANT ACTIVITIES

Among the R&D activities during the second half of the 1940s were three that were significant for their later impact on space transportation. One was the continued interest in rockets by Rand analysts after completing initial studies for the Air Force and during the period of emphasis on air-breathing propulsion. By 1949, when the Air Force again asked Rand to examine satellites, they had prepared an extensive report on the potentialities of rockets including long-range ballistic missiles, an important planning step towards the intercontinental ballistic missiles (ICBM) of the 1950s.

The second activity was experiments sponsored by both the Air Force and Navy on liquid hydrogen-oxygen, conducted at Ohio State University, Aerojet Corporation, and the Jet Propulsion Laboratory of the California Institute of Technology. Although the work was done with small rockets and not carried very far, the results indicated that high exhaust velocities could be attained, regenerative cooling with liquid hydrogen was possible, liquid hydrogen could be pumped, and the pump's ball bearings could run directly immersed in liquid hydrogen without

lubrication. This technology was shelved as attention turned to more conventional propellants for missiles.

The third activity was vehicle tests by Convair to obtain better rocket structural data. Convair engineers, like others, were greatly hampered by the lack of structural data beyond the A-4. To fill this need, Karl Bossart proposed to build and fly ten test vehicles incorporating some ideas for reducing structural or empty mass. The program began in 1947 but funding was soon cut and the number of vehicles reduced to three. These were flown at White Sands during the latter part of 1948. The vehicles contained three features: very lightweight tanks which were thin-walled and pressure stabilized, a concept proposed by Oberth in the 1920s but independently conceived by Bossart; elimination of the insulation jacket for liquid oxygen to save weight; and use of swiveling nozzles, first used by Goddard, to control the pitch and yaw of the vehicle. The flight tests were not an outstanding success but none of the problems were caused by the three features, all of which were incorporated into the Atlas, the first U.S. ICBM. (6)

To sum up to 1950, there were a number of proposals for space flight but little acceptance. Rocket engine performance was relatively low with durability and reliability uncertain. Vehicle empty mass was still relatively high and many improvements were needed to increase range. More flight data were needed. In short, there was too little experience and confidence in rockets to create much serious interest in space flight. A stronger motivation was needed and it did not come until the first part of the 1950s.

MISSILE DEVELOPMENT AND SPACE PROPOSALS

Samuel Hoffman, president of North American Aviation's Rocketdyne division that first developed large U.S. rocket engines, saw the first half of the 1950s as preparation for ballistic missiles and space travel and the second half as development of ICBMs and the start of the space age. Gen. Bernard Schriever, who managed the Air Force's missile developments during the 1950s, saw the decade as the golden age of advancing rocket technology. (7)

The decade began with space enthusiasts apparently no closer to their goal than

before and with air-breathing propulsion favored over rockets for long-range missiles. Weapons development and scientific interests, however, brought rapid changes by mid-decade. The military swung back to rocket missiles in 1953-54 when a breakthrough in thermonuclear weapon development indicated that a much smaller payload than heretofore thought necessary--about 700 kilograms--would be effective for strategic use. In 1954 the Atlas ICBM was selected for intensive development and within a year there were two ICBMs and two intermediate range ballistic missiles (IRBM) under development by the Air Force and Army. Funding jumped from \$3 million in 1952-53 to \$161 million in 1954-55 and continued to rise.

The stepped-up military missile development spurred space enthusiasts also. A number of proposals and fascinating descriptions of things to come appeared in technical meetings and the media. One of the most noteworthy was the series of articles in Colliers by von Braun and others in 1952-54 which was later published as a book.⁽⁸⁾ On the technical side were papers dealing with all aspects of space transportation including not only the vehicle with its propulsion, structure, and guidance systems but also the hazards man might experience in space such as high accelerations at take-off, weightlessness, hard vacuum, meteorites, and radiation. Attention to the return phase of flight also increased; winged, rocket-powered vehicles were discussed independently by Nonweiler (1951), von Braun (1952-54), Ehrlicke (1952-54), Romick (1954), and Crocco (1954).⁽⁹⁾ Crocco entitled his paper "The Crucial Problem in Astronautics: Recovery of Multistage Vehicles." He argued that economics dictated that each stage be a complete flying machine capable of ascending into space and returning safely to earth. His proposal of a step-by-step increase in flight capability was reminiscent of Valier and Tsiolkovskiy. The problem in the mid-1950s, however, was that all the big money and priority--and hence technology--were focused on expendable military missiles.

In the midst of all the mounting optimism and effort to gain political and public support for space flight, there were some with a different view. One was Jonathan Leonard, science editor of Time magazine, who ridiculed the prospects of space

flight by pointing out its many problems in an article in Life magazine: "Space, Its Enough to Make the Blood Boil." (Life, Aug. 31, 1953). Among engineers who urged caution in making overly optimistic space proposals, was Milton Rosen, director of the Viking sounding rocket program, who knew the practical problems from first-hand experience. In several meetings, he spoke on the "margin of error," where he pointed out that small decreases in rocket propellant flow or thrust could make big differences between predicted and actual performance. In 1955, he and von Braun clashed publicly. The event was the second symposium on space flight at the Hayden Planetarium of the American Museum of Natural History where von Braun was scheduled to present a step-by-step development approach and Rosen was to follow with a "down-to-earth" view. The coordinator, Willey Ley, wanted to drop Rosen's paper for fear that it would turn people away from space flight, but von Braun took the opposite view: a good argument would create interest. He was right, for the session made the front pages of New York news-papers and the cover of Time magazine.⁽¹⁰⁾

HELP FROM SCIENTISTS

In 1953, space advocates got a big break when the use of satellites to study space phenomena was recommended by a group of scientists planning the International Geophysical Year (IGY) activities to start in mid-1957. The idea of a satellite for scientific research gained government acceptance and by mid-1955 both the Soviet Union and the United States announced plans for IGY satellites.

SPACE BECOMES AN ACCEPTABLE WORD

The U.S. plans for a scientific satellite were limited to a very modest effort and included the development of a special launch vehicle--the Vanguard. The vehicle development, managed by the Navy, was not to interfere in any way with the high priority military missile developments. In fact, during the following years, emphasis on missile development was so great that a general anti-space attitude developed among U.S. Government officials. Anyone proposing a government program that mentioned space was inviting a budget cut. A typical example of this attitude was Schriever's experience after a talk he gave at a rocket

meeting in San Diego in February 1957 in which he mentioned that the missile program was creating a foundation for space. The following day he received a telegram from Secretary of Defense Charles Wilson ordering him never to use the word "space" again in any of his speeches.⁽¹¹⁾ This attitude changed overnight, of course, when Sputnik flew in October. By the time of Sputnik there were six U.S. missiles under development--Jupiter, by the Army; Polaris, by the Navy; and Thor, Atlas, Titan, and Minuteman by the Air Force--and all were larger and had greater payload capability than the U.S. satellite booster, Vanguard. Funding for the missiles was \$1.3 billion in 1954-57 and was still climbing. President Eisenhower and the Department of Defense kept these missile programs strictly on surface-to-surface military requirements, much to the disappointment of space enthusiasts.

FEASIBILITY OF THIN-WALL TANKS

The first Atlas flew in 1957 and the flight, generally regarded as a failure, was really a great success for demonstrating the feasibility of Bossart's thin-wall, pressure-stabilized tanks incorporated in the missile. During the first flight, the exhaust flames severed a control cable in the engine compartment causing the missile to tumble violently while still in the atmosphere. In spite of the very heavy aerodynamic loads imposed on the tanks and structure, they held--a convincing sight to many. Some engineers, however, remained unconvinced and prominent among them were members of von Braun's team at the Army Ballistic Missile Agency (ABMA), who were as conservative in their designs as bold in space proposals. Later, when Atlas was selected for Mercury flights, the ABMA engineers kidded Bossart: "My God, John Glenn is going to ride in that contraption? He should be getting a medal just to sit on top of it before he takes off!" Once, during a visit of ABMA engineers to San Diego, Bossart and his associates decided to show them just how tough the Atlas skin was. They pressurized a rejected Atlas tank and invited their visitors to knock a hole in it with a sledge hammer. One tried and the instant rebound of the hammer from the undamaged surface narrowly missed taking an ear off.⁽¹²⁾ The ABMA engineers remained unconvinced about thin-wall, pressure-stabilized tanks and all of their designs,

including Saturn, reflected their belief in relatively heavy, massive structures. The light Bossart tanks, however, were a breakthrough in the problem of building light vehicle structures and played an important role later in gaining acceptance for the use of low-density liquid hydrogen in upper stages.

LARGE ENGINES AND RELIABILITY

Although missiles received top priority, the Air Force far-sightedly supported R&D on larger engines, obviously with manned space flight in mind. In 1955, Rocketdyne received an Air Force contract on the feasibility of an engine of 1.3 meganewtons (300,000 lb thrust), the E-1, but it was never built. The same year, Rocketdyne announced that a single engine developing 4.5 meganewtons (1 million lb thrust) was feasible. In 1956, a panel of the Air Force's Scientific Advisory Board recommended a study of engines of 22 meganewtons, far larger than any currently planned. In 1958, the Air Force awarded Rocketdyne a contract for the preliminary design of a 4.5 meganewton engine, designated the F-1. Later in the year, NASA took over the project, increased the desired thrust to 6.7 meganewtons, and held another competition which Rocketdyne won. A development contract for the engine began in January 1959.

During the development of the ICBM and other rocket engines during the 1950s, a recurring problem was a phenomenon called combustion instability or combustion pressure oscillations. These oscillations greatly increased heat transfer and quickly burned out normally-cooled engines. A great amount of research was done on combustion oscillations but general understanding remained limited. The ICBM engines overcame this problem and became reliable, but during F-1 engine development in the early 1960s the problem rose again. It was eventually solved but combustion instability was generally regarded as one of the biggest threats to reliability during engine development and testing.

HIGH ENERGY PROPELLANTS

The first and major liquid propellant combination used in the IRBMs and ICBMs

was jet fuel (kerosene)-liquid oxygen, and performance was reasonably high. During the 1950s, however, there was considerable interest in liquid propellants capable of producing higher performance, but none appeared suitable for military missiles where readiness and logistics were major factors. In 1950, researchers at the NACA Lewis laboratory chose liquid hydrogen as a promising high-energy fuel and planned to extend the technology of the 1940s, but research was hampered by the lack of an adequate liquid hydrogen supply. This problem was overcome by the mid-1950s and experiments were conducted on the regeneratively cooled engines of a practical size. The laboratory's associate director, Abe Silverstein, became enthusiastic about the potentiality of using liquid hydrogen for high-altitude aircraft as well as rockets. His familiarity with hydrogen from Lewis experiments with both rockets and aircraft was to play an important role in a key decision in late 1959, to be discussed later.

In a separate activity, Clarence Johnson, famed aircraft designer, completed his development of the U-2 and became interested in the possibility of using liquid hydrogen in an advanced aircraft to surpass the U-2's altitude performance. He proposed this to the Air Force in early 1956 and the Air Force became very interested. A special project was established and over a hundred million dollars was spent over the next two years on various aspects of hydrogen fueled engines and aircraft, including financing the construction of three sizeable hydrogen liquefiers. Although liquid hydrogen proved to be reasonably easy to handle, Johnson became disillusioned over the aircraft's range and logistic problems. The project faded in 1958 but its Air Force managers proposed to use the technology and facilities to develop a hydrogen-fueled rocket. This became the RL-10 engine developed by Pratt & Whitney and was initiated in August 1958. Independent of the Air Force's hydrogen aircraft project, Krafft Ehrlicke proposed a hydrogen-oxygen upper stage for Atlas for space applications. The proposal, made in late 1957, was not selected for development until August 1958. Powered by two RL-10 engines, the Centaur became the first upper stage to use liquid hydrogen-oxygen, the same combination advocated by Oberth in the 1920s. Like the Atlas, Centaur used Bossart's thin-wall, pressure-stabilized

tanks sharing a common bulkhead and it has been one of the most successful stages in the space program.

During development of the hydrogen-oxygen RL-10, combustion instability problems were not encountered. The principal engineer, Richard Mulready, independently conceived the idea of operating the hydrogen pump's ball bearings immersed in liquid hydrogen. This was the same concept shown to be feasible at Ohio State University a decade earlier, indicating once again that similar innovations spring from more than one source.

TURMOIL AND ORDER, 1958-59

The 1958-59 period was one of great space planning activity, competition among government groups for a role in space, and the emergence of the basic space transportation "stable" of boosters that has served the space program well. The Russian space accomplishments in 1957-58 made it amply clear that their boosters had greater space payload capability than U.S. vehicles. There was a popular outcry in the United States, aided and abetted by space enthusiasts, to catch up and surpass the Russians. Thus, foreign competition, with attendant fears of losing technological and defense advantages, did what years of previous space proposals had failed to do: gain political and public support for more than a minimal space program.

The low-budget, low-priority Vanguard program was plagued with development problems at the time of Sputnik, and in November the Army was given permission to prepare a back-up vehicle. The following month turned out to be a low point for U.S. space plans. After Sputnik, Vanguard received the full glare of U.S. public attention and the launch of its third test vehicle in December was a disaster. The von Braun team, who had been studying large launch vehicles since 1956, chose that month to submit an ambitious proposal to the Department of Defense entitled "A National Integrated Missile and Space Development Program" but it received little attention. Also in the same month, the Air Force made a move towards a space role by establishing a directorate of astronautics headed by Brig. Gen. Homer Boushey, but it was abolished three days later on curt orders from President

Eisenhower, then in Paris. Boushey had the dubious honor of heading the shortest-lived office in the Air Force. (13)

The U.S. space picture brightened in early 1958 with the successful launching of Explorer I and Vanguard I. In this atmosphere of success, ABMA revised and re-submitted its proposal in March. It listed eleven space boosters ranging from the Vanguard and ABMA's Juno I to a second generation orbital carrier of two stages, both recoverable, with a payload of 23,000 kilograms. The report became enmeshed in a web of other space planning activities. In February, the Department of Defense established the Advanced Research Projects Agency (ARPA) as the focal point for all military space and other advanced projects. In its initial planning, ARPA included scientific satellites but in early April, this was changed by Presidential directive; the NACA was to become the nucleus of a new civilian space agency proposed to Congress the same month.

In an earlier bid for a space role, NACA organized a space technology planning committee headed by Dr. T. Guyford Stever. The committee organized seven working groups, one of which was on vehicles--headed by von Braun. In April, von Braun's eager staff jumped the gun on the working group by submitting an "interim" report to the Stever committee that was essentially the same report, even to the title, as submitted earlier to the Department of Defense. In addition to the space vehicles, the report proposed an ambitious space program including a 50-man, permanent space station; flights to the moon; and interplanetary expeditions to Mars and Venus. When the report reached quiet, conservative NACA headquarters all hell broke loose and the report quickly acquired a tag forbidding it to leave the premises. ABMA asked permission to distribute the report but NACA gave permission only if each copy bore a disclaimer that it was not an official NACA document. Von Braun soon got his working group together, however, and it included members from NACA the military, and industry. Their final report, in July, contained a vehicle program of 15 boosters in 5 generations of development. The first three generations were based on on-going missile developments. The fourth generation was ABMA's Juno V with four Rocketdyne E-1 engines developing 6.8 meganewtons, with an alternate configuration of a cluster

of nine ICBM engines for the same total thrust. The fifth generation included larger vehicles--13 to 26 meganewtons, with high-energy chemical and nuclear upper stages. The same month, Silverstein, a member of the Stever committee and von Braun's working group, and head of NACA space activities, submitted a rather modest budget request for a start on the booster program. Included were funds for a large engine development, a cluster of existing engines, and work on high-energy chemical upper stages--the latter for unmanned flight.

While NACA was planning a space program, ARPA had acquired an aggressive group of experts who moved quickly towards large boosters. One, Richard Canright, believed that a cluster of existing ICBM engines was the fastest way to build a large booster and further, that multiple engines would enhance reliability. Canright convinced the von Braun team of the value of this approach rather than their favorite design using four proposed E-1 engines. In August 1958, ARPA directed the Army and ABMA to develop the first stage of a large booster using the multiple engines, first called Juno V and later Saturn I. Also in August, as previously mentioned, ARPA directed the Air Force to start development of a hydrogen-oxygen engine and the Centaur upper stage for Atlas.

In January 1959, NASA and the Department of Defense presented a joint report on a national space vehicle program to the National Aeronautics and Space Council and the President. In the report, the current vehicles--Vanguard, Jupiter C, Juno II and Thor-Able--were criticized as being hurriedly assembled under pressure, not very reliable, and not suitable for future space needs. A series of general purpose vehicles, with an estimated useful life of 5 years, were described: Atlas-Vega, Atlas-Centaur, Juno V (Saturn I), and Nova. Two other vehicles were mentioned, the all-solid propellant Scout for small payloads and Atlas-Hustler for military missions. In the months to come, NASA dropped Atlas-Vega in favor of Atlas-Centaur and the military replaced Atlas-Hustler with Atlas-Agena.

Juno V, DoD's large vehicle, was shown with two configurations in the report, differing only in the third stage. The initial third stage was to use kerosene-oxygen like the two lower stages but

would be later replaced by a hydrogen-oxygen stage using the Pratt & Whitney engines under development.

Nova was NASA's large vehicle concept which would use four F-1 engines in its first stage and one in the second stage. The third and fourth stages would use hydrogen-oxygen engines. NASA saw Nova as a means for transporting man to the surface of the moon and returning him safely to earth.

One of the problems facing government planners was not so much a lack of ideas for space transportation but how to select the best, consistent with the overall objectives of the national space effort. In this respect, the rest of 1959 was a turbulent period for large booster proposals but the issues were resolved by the end of the year.

Events during the spring and summer of 1959 were frustrating for military planners of large space boosters. Work proceeded at ABMA on the first stage of Saturn I, but a decision could not be reached on Saturn's upper stages, particularly after the Army began to consider the Air Force's Titan as a second stage. The Air Force wanted no part of this, for not only would it divert some Martin effort away from the Titan missile, it would also bring the Army into its contractor territory. The Air Force offered to manage the development of a Titan as a second stage for Saturn but the Army wanted no part of that arrangement. Another perturbation was Air Force plans for a larger version of a Titan, called Titan C, which would boost a winged vehicle into a skip-glide path. This was Dynasoar, the first U.S. project initiated for a manned winged vehicle for eventual flight into orbit and return.

While the interagency wrangling over Titan as a second stage for Saturn was going on, a much worse problem for Saturn arose. Dr. Herbert York, newly appointed to the Department of Defense's highest position in research and development, began taking a hard look at large boosters and military space plans. He believed that even after several years of effort the military had not made a case for manned space flight. He saw such flights as NASA's mission and ABMA's emphasis on large booster development as seriously interfering with the Army's primary mission of ground warfare.

He also questioned the need for Saturn in view of the Air Force's plans for Titan C. York was able to win Secretary of Defense Neil McElroy to his view and he sent ARPA a message that he was cancelling Saturn. (14) ARPA tried to save Saturn by offering it to the Air Force but this did not succeed. The remaining alternative was to transfer Saturn to NASA which ABMA had successfully resisted for some time even though the transfer was favored by both the Secretary of Defense and the President.

York's critical assessment of the military role in space forced an issue that had been simmering for some time: how many large space boosters could the Nation afford to develop? York established a review committee with himself and NASA's Hugh Dryden as co-chairmen to consider the three large boosters: the Army's Saturn, the Air Force's Titan C, and NASA's Nova. Agreement was quickly reached that only one should be developed and Saturn emerged as the winner. Titan C was shelved and Nova was considered too far in the future to be competitive with Saturn. York agreed and began negotiating for the transfer of ABMA to NASA: in October, President Eisenhower approved the transfer by executive order.

Remaining unsettled after the selection of Saturn was its upper stage configurations. ABMA abandoned its initial proposal to use Titan as the second stage when further study of the long, slender configuration indicated severe structural bending load problems. A second stage with a larger tank diameter than Titan I but using Titan's engines was proposed. NASA favored using hydrogen-oxygen and pushed for the development of a 668 kilonewton hydrogen-oxygen engine that had been under study for some time. This engine, with a higher thrust specified, was the J-2 and its development started in early 1960.

In December 1959, with the issue of Saturn's upper stages still unresolved, NASA's Richard Horner appointed a NASA-Dod "team" headed by Silverstein to make recommendations on Saturn upper stages and a Saturn development plan. Von Braun, a member of the team, initially argued strongly for using tried and proven kerosene-oxygen engines in the second stage. Silverstein, however, was convinced--not only from his own experience

and judgment but also by Saturn analyses by Eldon Hall--that all upper stages should use liquid hydrogen-oxygen. This was a very bold view at the time, for the only project underway using hydrogen-oxygen was Centaur and it was in the early stages of development. Silverstein won von Braun and others on the team to his view and in mid-December the team recommended that the first and follow-on Saturns use liquid hydrogen-oxygen in all the upper stages.⁽¹⁵⁾ Also recommended was a "building block" approach for upper stages in which, for example, the second stage of the first Saturn could be used without modification as the third stage of a larger, follow-on Saturn. The follow-on Saturn turned out, after a number of configuration studies, to be Saturn V. Thus the basic decision of the Silverstein committee to use hydrogen-oxygen and the development approach of multiple use of stages were key factors in the timely development, performance, and reliability of Saturns I and V.

To sum up the 1950s, there were many imaginative descriptions of space missions and some realistic proposals. These raised sparks of interest but not sufficient flame to support a project until scientists provided the reason and motivation. The use of space for science brought political and public acceptance of a very modest space effort until foreign competition stimulated a large space program. Space transportation was able to get a rapid start by using missiles and technologies developed during the decade. Competition between government groups, coupled with political and public will, became the crucible for ensuring the emergence of a strong and sound program. Innovations, such as those by Bossart, and bold decisions, such as the one by Silverstein to use hydrogen-oxygen in all Saturn upper stages, allowed quantum jumps in technology and the development of successful vehicles.

In conclusion, the lessons of the 1950s can apply to future successful space projects. They need the right mix of: realistic proposals of what can be done and the benefits to be derived, in order to create enthusiasm and desire; timely and realistic plans in tune with political, economic, and social interests, to gain acceptance; research and technology, to make developments feasible, augmented by

innovations and bold, sound decisions if needed to overcome major obstacles; sound engineering and management, to develop and fly reliable space vehicles; and life support and protection systems to ensure that astronauts can fulfill their role during the mission.

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