Chapter 4

Advanced Rockets

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Chapter 4
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INTRODUCTION

NASA is currently studying several proposed advanced crew-carrying launch systems that would help augment or supplant the current Shuttle fleet as it ages. They include the NASA Advanced Manned Launch System (AMLS-previously called Shuttle II), a Personnel Launch System (PLS), a crew-carrying version of the joint DoD/NASA Advanced Launch System (ALS), and a crew-carrying stand-alone Liquid Rocket Booster (LRB) system. NASA expects the AMLS to supplant the current Shuttle, but provide less payload capacity. The PLS or crew-carrying ALS could help augment the Shuttle if either is introduced before the Shuttle is retired. The intent of each concept is to provide for more cost-effective, reliable human access to space.

ADVANCED MANNED LAUNCH SYSTEM

NASA's Langley Research Center is leading the AMLS program, which will define advanced crew-carrying launch system concepts, including their development, system and operational characteristics, and technology requirements. The AMLS program could by the year 2005[1] lead to a vehicle significantly different than the Shuttle. NASA will compare the AMLS and the PLS with the option for an improved Shuttle, under study by the Johnson Space Center (JSC), and decide how best to proceed. NASA is evaluating five AMLS concepts (figure *4-1)* listed below in order of increasing technological risk:[2]

- An *expendable in-line two-stage booster* with a reusable piloted glider.[3] This configuration at first appears similar to the U.S. Dyna-Soar[4] concept of the early 1960s, which would have been launched atop a Titan III, but would carry a larger crew. Dyna-Soar would have carried one or two pilots.[5] The European Space Agency and the Japanese NASDA have selected this approach for their spaceplanes Hermes and HOPE, respectively (see below). It might be possible to use an ALS to launch an AMLS orbiter.
- A *partially reusable drop-tank vehicle* similar to the fully reusable rocket concept described below, except that hydrogen propellants for the piloted orbiter are carried in expendable side-mounted drop tanks and the payload is carried in an internal canister. This configuration eliminates the need for a separate propulsion and avionics module seen in the next option, thus reducing its relative development and operations costs.
- A *partially reusable vehicle* with a glider atop a core stage, which has expendable tanks but recoverable engines and avionics. The core stage would be side-mounted on a reusable glideback booster. This partially reusable configuration may be economical at moderate launch rates.
- A fully *reusable rocket* with a piloted orbiter parallel-mounted (side-by-side) to an unpiloted glideback booster. This vehicle would be shorter than the in-line or glider atop a core stage version, making launch preparation easier. To facilitate payload integration or swap-

[1] This tacitly assumes that the present Shuttle system, even with improvements and possible fleet additions, will be nearing the end of its useful life (as a result of wearout and/or attrition or cost reduction potential of new crew-carrying systems) between 2005 and 2010. Some argue that the present Shuttle system, having made its first flight in 1981, is still a relatively new aerospace system, and with well-considered improvements and additions to the fleet could serve effectively until the year 2020. In either case, a decision to proceed with an AMLS would not be required until at least 1995.

[2] And thus roughly in order of increasing initial development cost. Total life-cyle costs would vary greatly, however, depending primarily on reusability and flight rate.

[3] This vehicle could be very tall, making launch preparation difficult. Its design would depend on the booster selected and on the mission requirements of the orbiter. In addition, the orbiter engines could not be ignited on the launch pad prior to liftoff and must be fired in flight after stage separation, which would eliminate an abort mode on the ground. (An alternative that would remove this concern would be to require only an orbital maneuvering system in the orbiter, as in the Soviet shuttle and rely on the booster to place the orbiter in orbit.) Another obvious disadvantage is that this concept takes a step back from reusability.

[4] See ch. 5 of this report, or for a much more detailed description see "The Hypersonic Revolution—Eight Case Studies in the History of Hypersonic Technology," vol. 1, case 11, Richard P. Hallion (cd.), WPAFB, Ohio, 1987.

[5] The PLS concept could resemble the Dyna-Soar.

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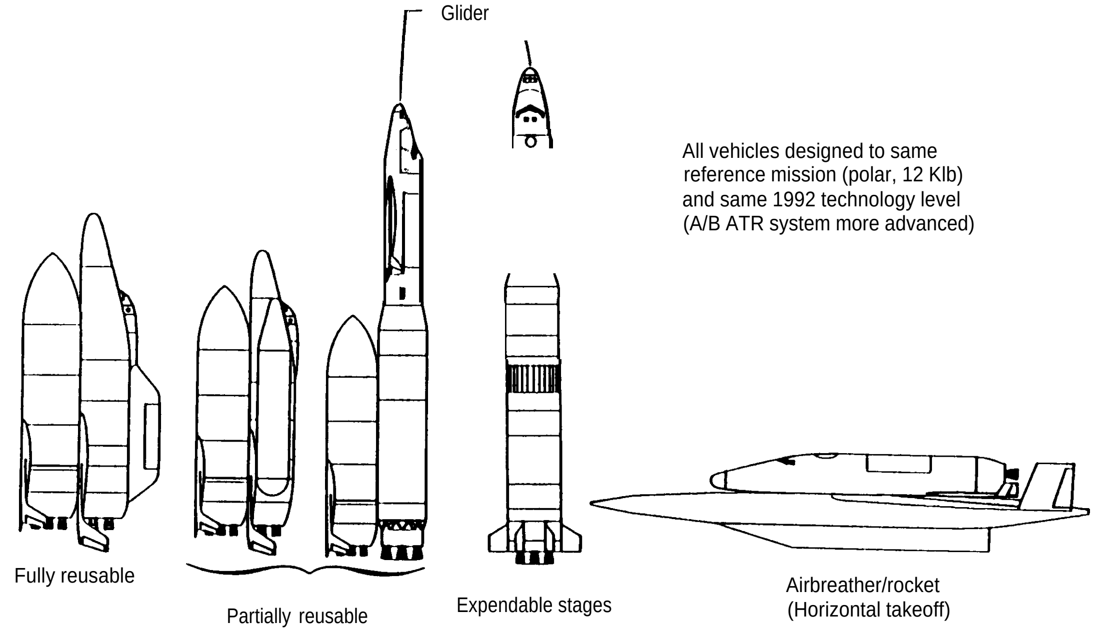
Figure 4-1-Advanced Manned Launch System Concepts



KEY: A/B = airbreather; ATR = air-turbo-rocket.
SOURCE: National Aeronautics *Space* Administration, Langley Research Center.

ping, the orbiter would have a payload pod atop its fuselage, rather than an internal payload bay. The second-stage engines would be on the orbiter. Fully reusable configurations such as this are believed (but not proven) to minimize cost per launch at high launch rates. The fully reusable cryogenic tanks on both booster and orbiter are a critical technology requirement for this option.

- A *horizontal takeoff and landing air-breather/ rocket,* which would resemble the German two-stage Saenger spaceplane (see later discussion in this chapter). This configuration would utilize the same technologies as for the AMLS rocket concepts summarized above, except that it would use an advanced air-turbo-rocket (ATR) air-breathing engine for the first stage. This vehicle would be fully reusable.

These alternate configurations also span a wide range of reusability. The higher the anticipated launch rate, the more attractive reusability becomes from the standpoint of cost.

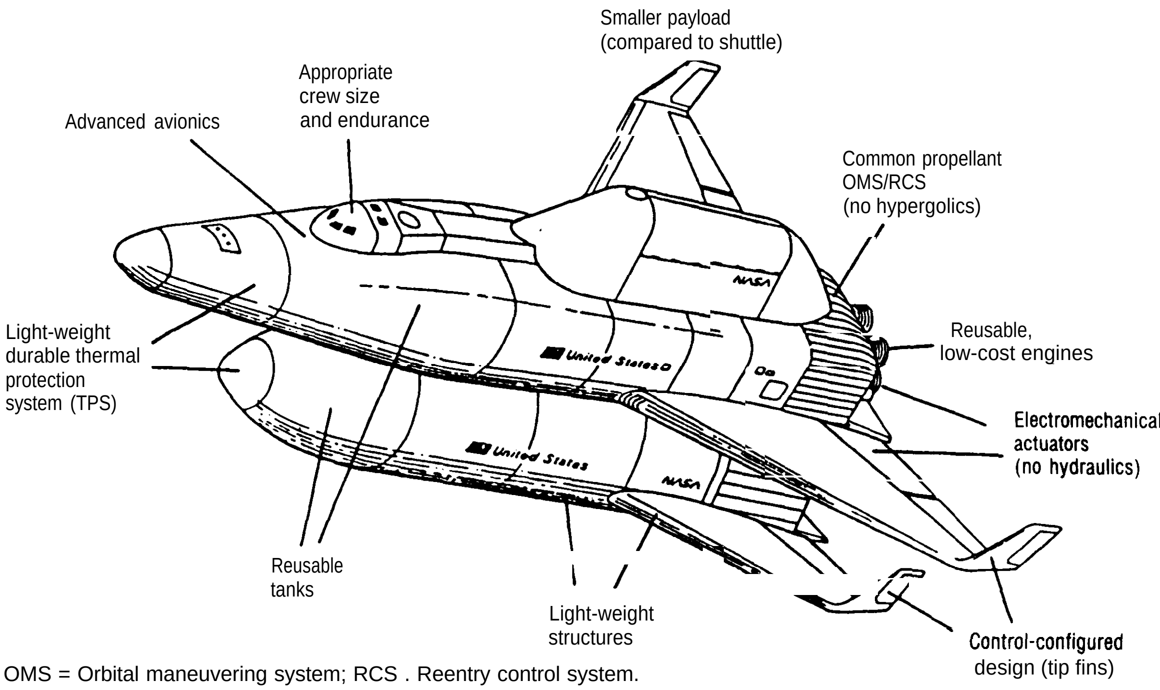
Because development of an AMLS vehicle need not begin until the mid to late 1990s, NASA could defer a decision on whether to start AMLS development until it has completed preliminary designs of alternative vehicles in sufficient detail to estimate technological risk and life-cycle cost.

Critical technology needs for all AMLS concepts include:

- light-weight primary structures,
- reusable cryogenic propellant tanks,
- low-maintenance thermal protection systems,
- reusable, low-cost propulsion,
- electromechanical actuators,
- fault-tolerant/self-test subsystems, and
- autonomous flight operations.

Figure 4-2 illustrates typical technology needs for a fully reusable version of the AMLS. Although meeting these advanced technology requirements would be challenging, none is considered a "showstopper." Thus, most experts feel that this technol-

Figure 4-2--Role **of Technology in Advanced Manned Launch System (reusable version)**



KEY: OMS = Orbital maneuvering system; RCS . Reentry control system.

SOURCE: National Aeronautics and Space Administration, Langley Research Center.

ogy could be available in time for an AMLS, since the AMLS would not be needed until after 2005.

PERSONNEL LAUNCH SYSTEM (PLS)

The Personnel Launch System is a new concept that stems from "The Next Manned Transportation System" (TNMTS) study organized by NASA Headquarters. The TNMTS, a 2-year effort that began in spring 1989, is now analyzing five primary approaches:

1. purchase additional orbiters,
2. improve the current Space Shuttle system (Shuttle evolution),
3. develop a Personnel Launch System (PLS),
4. develop advanced rocket-powered launch vehicles (AMLS), and
5. develop advanced launchers based on air-breather technology,

JSC was named the lead center for the PLS option as well as for Shuttle evolution work. NASA'S Langley Research Center will examine a lifting body option[6] for the PLS. The NASA centers, Marshall and Kennedy, would have major roles in developing a PLS but responsibilities for various tasks are still to be determined.

As the PLS concept is so new, little can be said about it, including its potential cost. It was prompted by the desire for a crew-carrying vehicle that could be available sooner than an AMLS and would also be cheaper and simpler. It could range from a small three- or four-person transport (similar to the space taxi and return concept described in ch. 6) to a vehicle sized to carry as many crewmembers as the present Shuttle.

A PLS vehicle could in principle be designed to be highly flexible and might also be configured to carry cargo as well as people. For example: it might be designed to carry small logistics payloads for the

[6] See ch. 6 for descriptions of lifting bodies.

Space Station. It could also be designed to launch capsules capable of providing emergency rescue from the Space Station.

CREW-RATED ADVANCED LAUNCH SYSTEM

Several aerospace experts have suggested that should the United States decide to build the ALS, it would be prudent to give this vehicle the capability to launch people as well as cargo. If affordable, resilience in human access to space is a desirable feature, since today people can only be launched on the Shuttle, which continues to be susceptible to major delays or loss from attrition.

The ALS Civil Mission Needs Statement requires that the ALS "provide a highly reliable (above 99 percent), fault-tolerant launch system capable of having a man-rated variant."[8] ALS stages or components could be used in an AMLS, and a crew-rated ALS launch vehicle could be used to launch a crew rescue vehicle (CERV-discussed in ch. 6) or alternatives to AMLS that have been proposed by industry (figure 4-3). Finally, it might be used to launch a PLS.

Current crew-rating procedures require the use of greater strength margins in structural components, additional redundancy in subsystems, and added oversight and paperwork in the design, manufacturing, and operation of a launch vehicle compared to non-crew-rated vehicles. '" Some officials in the ALS program, however, feel that the ALS would be so highly reliable and robust that the additional development cost or time required for crew-rating the ALS would be small. As proposed, the ALS, which could use all-liquid propulsion, would be designed for high reliability and would include such features as "engine out" capability (the ability to complete the mission even if an engine fails to operate), redundant electronics, and other high reliability features; and thus is intrinsically designed much like a crew-rated version.[11] At present, there no "ALS crew-rating program" per se. Although the work statement for the ALS contractors does state that the ALS must "be capable of flying manned cargos,' none of the contractors have yet found a need to identify different cargo or crew-carrying configurations. '2

Along with improved resiliency, a crew-rated ALS would have three additional advantages:

1. if the crew-rated ALS were designed to carry a capsule like Apollo, crew escape could be easier than with the Shuttle, and escape could be possible during the whole trajectory, unlike the Shuttle from which escape is impossible during most phases of liftoff;
2. the crew-rated ALS could launch a crew-carrying PLS; and
3. there may be cases where it will be necessary to take personnel and cargo up to the Space Station but not down on the same mission. In that case, there is no need to risk an orbiter.

Redundancy in crew-rated launchers has many benefits, including improved resilience. But it would come at a cost. Policymakers would have to decide whether to saddle the ALS with the additional development and operating costs for crew-rating or

[7] Having redundant launch systems (usually of different technological heritages) capable of accomplishing the desired mission so that if one launch system has to standdown, another can rapidly be used in its place.

[8] Thomas M. Irby, "Status of the ALS Program," *Proceedings of the Space Systems Productivity and Manufacturing Conference-V*, Aug. 16-17, 1988, El Segundo, CA. Another ALS Systems Requirement Document states that the ALS design 'will not preclude human cargo' (Thaddeus Shore, SDIO).

[9] What makes a launch system "man-rated" is open to various interpretations. NASA is working on a consistent set of guidelines for crew-rating space systems. This document, still undergoing review, defines crew-rating as follows:

> A man-rated space system incorporates those design features and requirements necessary to accommodate human participants. This provides the capability to safely conduct manned operations, including safe recovery from any credible emergency situation Man-rating is the process of evaluating and assuring that the hardware and software can meet prescribed, safety -oriented design and operational criteria. It is an integral part of the design, development, verification, management and control process. It continues throughout the operational life of the system.

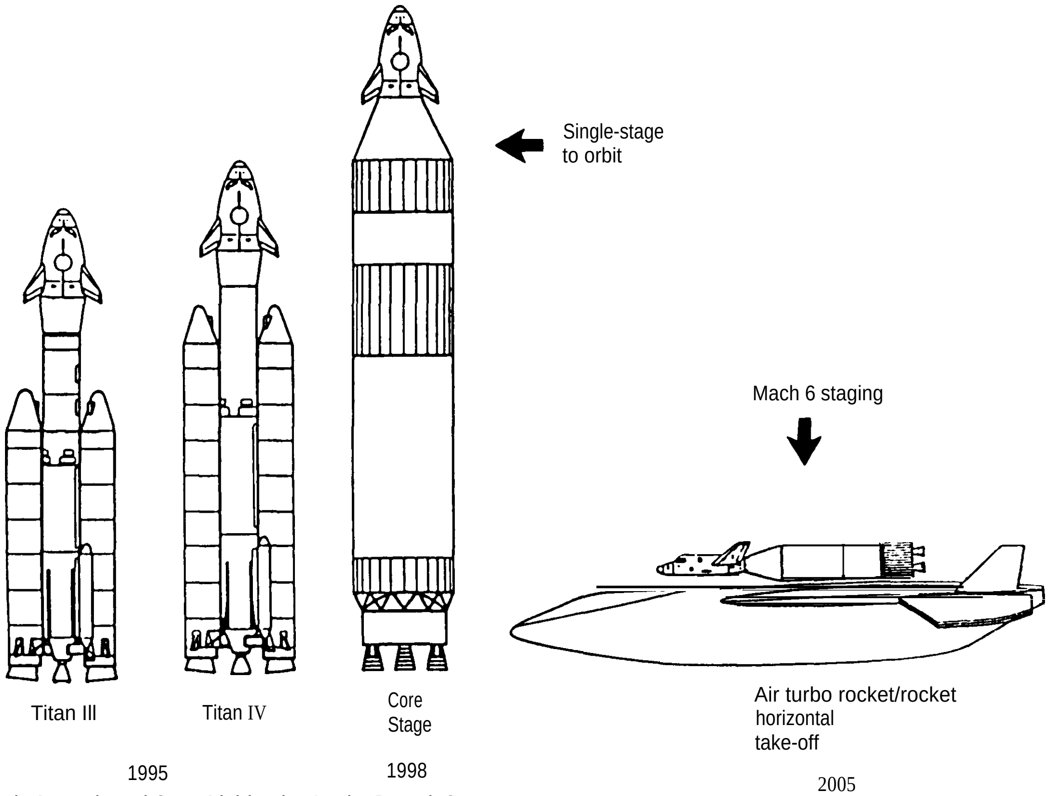
(Guidelines for Man-Rating Space Systems-preliminary, Advanced Programs Office, NASA Johnson Space Center, JSC-23211, September 1988, p. 5.)

[10] This would also m&e it more difficult to reach the ALS goal of reducing vehicle and operations costs.

[11] For very high-value payloads, many argue that a vehicle should be crew-rated anyway.

[12] One concern of ALS designers is that g loads for the ALS may reach as high as 6 or 7, which is survivable by humans but not very comfortable. In contrast, the Shuttle is designed for a maximum of 3 g's.

Figure 4-3--Crew Emergency Rescue Vehicle (CERV)/Space Taxi and Return (STAR)



SOURCE: National Aeronautics and Space Administration, Langley Research Center.

whether resilience would be better served by a PLS or a stand-alone LRB system.

STAND-ALONE LRB SYSTEM

If LRBs were developed as part of a Shuttle solid rocket booster replacement program, or in conjunction with an ALS engine program, these boosters could be used to propel a stand-alone system capable of carrying people to orbit. Because the engines would have already been developed, a launch system built around an LRB could be cheaper to develop than an entirely new launch system.

FOREIGN CREW- AND PASSENGER-CARRYING VEHICLE PROGRAMS

The United States and the Soviet Union are currently the only nations capable of sending people to and from space. The Soviet Union has recently developed a reusable space shuttle orbiter that is launched on its heavy-lift launcher, *Energia.*

The European Space Agency (ESA), Japan, the Federal Republic of Germany, and the United Kingdom are all in various stages of developing their own reusable launch systems, some of which, if successful, would be capable of transporting humans to orbit. The designs for these launch systems still exist largely on paper. Nevertheless, these countries possess a high level of technological capability and could develop crew-carrying vehicles if they wished to make the necessary investment, For these countries, building launch systems has become an important part of decreasing their dependence on the United States and the Soviet Union for reaching space. Developing crew-carrying capability would be a national achievement signaling their status as major space powers, able to develop and use a broader range of advanced technology.

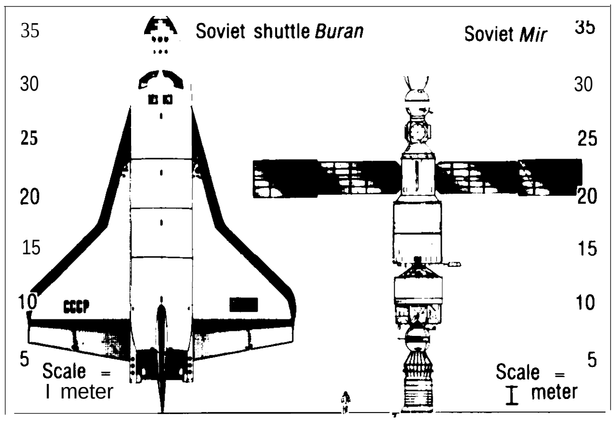
Non-U.S. concepts differ widely as to configuration, reusability, crew size, and payload capability, and their project status ranges from preliminary design, like the Hermes, to the Soviet *Buran*, which has already completed its first test flight. Except for the Soviet shuttle, none of these systems yet pose a competitive challenge to the United States. The United States should monitor the progress of these programs both for competitive concerns and cooperative opportunities in order to respond appropriate y.

Soviet Space Shuttle

The Soviet counterpart to the U.S. Space Shuttle made its maiden flight on November 15, 1988. Lifted into space by an *Energia* booster (presently the world's largest booster), the 100-ton shuttle named *Buran* (Snowstorm) remained aloft for two orbits of the Earth, some 3 hours and 25 minutes. The spacecraft is nearly identical in physical shape to that of its American cousin (see figure **4-4)**, but it does exhibit several key differences. The primary difference is that *Buran* lacks its own main engines, relying instead on propulsion provided by the *Energia* to place the shuttle craft into orbit. *Buran* also uses a set of small maneuvering thrusters to reach orbit and later deorbit.

Similarities between the U.S. and Soviet designs are striking. The delta wing, vertical tail structure, payload bay, window placement, as well as thermal protection patterns are common to both vehicles. Initial reaction from Western experts held that the identical profile of the two spacecraft had saved the Soviets years of development time and expense by copying U.S. plans. Soviet space engineers claim the similarity derives from the same mission objectives of both craft: ferrying people and payloads into Earth orbit and maneuvering from space to a runway landing. Soviet reports state the *Buran can* place 66,000 pounds of payload into orbit and return from space with 44,000 pounds. 's The Soviets claim that special-purpose missions using *Buran* can last up to 30 days. Eventually, four flights per year are envisioned using these shuttle vehicles.

Figure 4-4--Soviet Space Shuttle *Buran* and *Mir Space* Station



SOURCE: Teledyne Brown Engineering.

In some respects, the *Energia-Buran is* more versatile than the U.S. Shuttle. For example, the *Energia* rocket can launch an orbiter, or it can be launched without an orbiter, in which case it can carry a payload weighing more than 220,000 pounds. It has four reusable first-stage boosters clustered around an expendable second ("core") stage, which has four engines. First- and second-stage engines are ignited on the launch pad, and, because all engines use liquid fuel, they can be shut down on the pad or in flight to abort a launch if one or more fails to achieve sufficient thrust. In some cases the orbiter may still reach orbit, even if an engine has been shutdown during flight. In any event, the vehicle is expected to maintain controlled flight-to an emergency landing site if carrying crew, or to a place where it can ditch or crash without endangering people or structures.[14]

Perhaps the most interesting feature of the Soviet approach to winged space flight is the Soviet ability to use automated landing systems. *Buran's* first flight was unpiloted and relied on ground controllers for on-orbit maneuvering, *Buran* then used onboard computers to carry out an automatic approach and

[13]To a 100-nmi high orbit; see U.S. Department of Defense, *Soviet Military Power*, 1988.

[14]G. Gubanov, *Pravda*, July 30, 1988, 2d cd., p. 4. [in Russian]

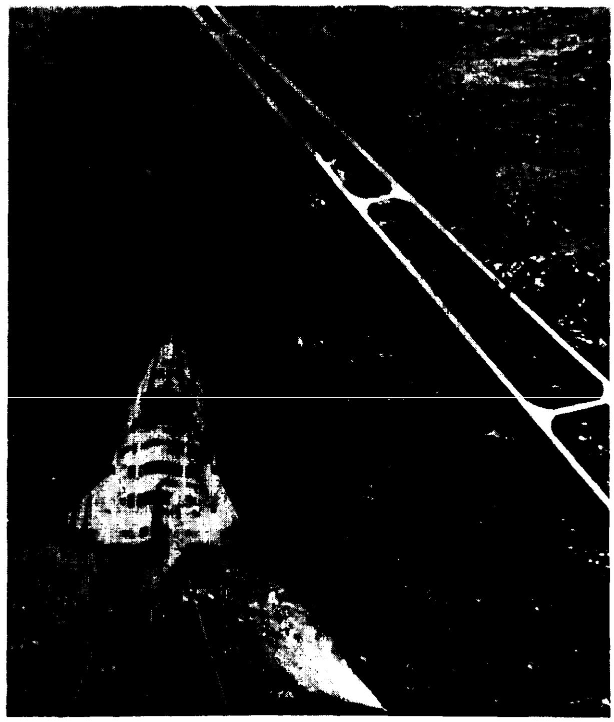
landing at a special shuttle runway at Baikonur.[15] Three parachutes slowed the shuttle vehicle to a stop.

By contrast, although the U.S. Shuttle fleet does carry some automated landing equipment,[16] astronauts to date have vetoed its use below a certain altitude. The Soviet technology used for *Buran's* automatic flight ability appears to be coupled to the hardware developed for the Tu-204, a new Soviet medium-range twin turbofan aircraft.

Reports remain sketchy as to overall capabilities of the Soviet shuttle design. Six Soviet shuttlecraft are believed to be in various stages of construction. Another shuttle, named *Ptichka* (little bird) is expected to be launched next. As many as 10 individuals can be accommodated in the *Buran* shuttle, Soviet experts have stated.

The Soviets have modified MiG 25 ejection seats for use in its space shuttle when it makes a piloted flight, Soviet engineers state that the ejection seats can even be used when the shuttle is on the launch pad. The maximum speed at which they can be used is Mach 3.[17]

Figure 4-5-Soviet Spaceplane



SOURCE: Royal Australian Air Fore@.

Soviet *Spaceplane*[18]

Still an enigma to the United States is the Soviet Union's subscale prototype spaceplane and what part it plays in their space program. This l-ton winged mini-spaceplane (see figure *4-5)* in its first four flights between 1982 and 1984 orbited Earth only once and touched down in water. It has by now possibly made a dozen flights.

The Soviet mini-spaceplane program resembles the effort undertaken in the 1960s in the U.S. Dyna-Soar program, and the European Hermes project presently underway. Some U.S. experts speculate that it was designed to evaluate the aerodynamic and reentry characteristics of the much larger Soviet shuttle. Others theorize that the plane could be built for quick launch and turnaround, as well as for occasional reconnaissance. A full-scale spaceplane, capable of runway landings, is expected to fly with two to three cosmonauts, launched by the SL-16 booster. Some experts have hypothesized that the spaceplane could serve as a crew escape vehicle attached to the Soviet *Mir* space station.

European Space Agency Hermes Spaceplane

This piloted shuttle has been championed by France as an effort to provide an independent, European, crew-carrying launcher. As a small, winged spaceplane 15 meters long with a wingspan of 10 meters, Hermes could carry a crew of three and slightly over 2 tons of payload to a 500-km orbit. The spaceplane itself originally was meant to be completely reusable but as now envisaged, the vehicle will have an expendable adapter called the Hermes Resource Module that will separate from the space-

15Recently, the Soviets have expressed concerns about their automatic systems, and cite this as one reason for delaying the next flight (which will carry no crew) until 1991. The first crew-carrying flight may not occur before 1992.

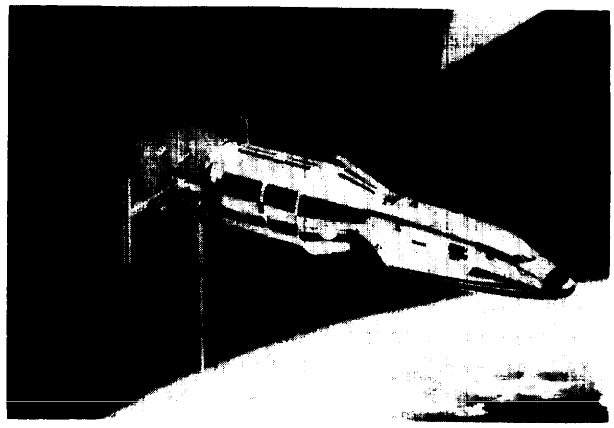
16The U.S. Shuttle is not fully automatic as pilots must brake and steer it on landing. Automating these tasks has been proposed, however--- ch. 2.

17*Space*, January-February 1989, p. 56.

18Peter M. Banks and Sally K. Ride, "Soviets in Space," *Scientific American*, February 1989.

plane and burn up during reentry. Current mission planning calls for an initial unpiloted test launch on an Ariane 5 in early 1998, crew-carrying flights beginning in late 1998 or early 1999, and regular operational flights twice annually starting in 1999 or 2000. Total development cost for the Hermes project is estimated at over $4.5 billion,[19] with most of the financing coming from France and the Federal Republic of Germany. Two vehicles would initially be built, leading to an eventual fleet of four. Each Hermes could make two to three flights per year. One recent Hermes concept is shown in figure 4-6.

F gure 4-6—European Space Agency Hermes Spacep ane



SO European pace Agency

Japanese HOPE

The Japanese National Space Development Agency (NASDA) is studying a concept called "HOPE" (H-II Orbiting Plane), an unpiloted winged mini-shuttle. HOPE would be launched atop the Japanese H-II launch vehicle, an indigenously designed and built expendable rocket, expected to fly in 1992 (see figure 4-7).

Japan is considering HOPE for several missions, such as delivery and return of materials from the Japanese Experiment Module (JEM) of the international Space Station, polar-orbital missions, and what the Japanese call "space technology experiments. The HOPE design still is emerging but current plans call for it to land horizontally. NASDA suggests a first flight date in late 1996.[20]

HOPE actually may be Japan's first step toward an autonomous piloted spaceflight capability early in the 21st century. A national "Advisory Committee on Space Plane' recommended a broad research and development plan for a fully reusable aerospace plane. The committee urged that the Space Plane "be promoted as an important national R&D project," but promised that the program would be opened to international cooperation in its early stages.

German Saenger

The Federal Republic of Germany is studying this two-stage launch vehicle (figure 4-8), which would be a piloted craft carrying a cargo plane piggyback into space. Stage 1 would be a large hypersonic aircraft propelled by six hybrid turbo-ramjets and would be designed to take-off and land horizontally at several large European airports. For flights without a crew, the second stage would be of an expendable cargo upper stage (" Cargos"), capable of placing 33,000 pounds into LEO or 5,500 pounds into GEO. Cargus would use a single LOX/LH2 engine, the same powerplant being developed for the Ariane 5 core. For piloted flights, a spaceplane called "Horus" (Hypersonic Orbital Upper Stage) would serve as Saenger's second stage. Its present configuration gives it the same basic shape as Hermes with twice as much volume. Designers plan for Saenger to operate as a ferry craft with limited orbital duration—perhaps not more than 1 day. Horus could lift 4,000 to 6,000 pounds of cargo, plus two pilots and four passengers to a 270-mile orbit at a 28.5-degree inclination. Horus would use two LOX/LH2 engines similar in size to the U.S. Shuttle's SSMEs.

A major incentive for developing Saenger is the potential reduction in space transportation costs. The West German Research Minister states that, in theory, Saenger has the potential of reducing the costs of placing payloads into orbit from about $3,500 per pound to $500 per pound. Recently, the

[19] "Canada Joins Hermes program, " *Aviation Week and Space Technology,* Mar. 13, 1989, p. 30.

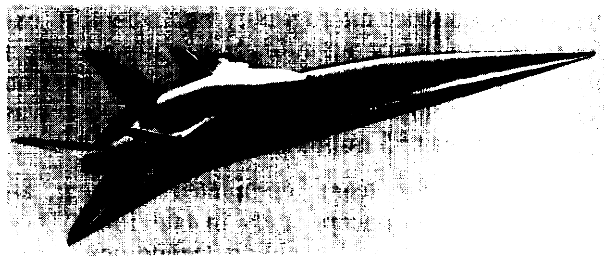
mst~eyw.K~debo,''Jw~e~ Refining Unmanned HOPE Orbiter for Planned 1996 Launch,' *Aviation Week and Space Technology,* Apr. 3, 1989, pp. 57-58.

Figure 4-7— Japanese HOPE

SOURCE: Japanese National Space Development Agency.

German Government agreed to fund the initial development work for Saenger with a first demonstration of components between 1993 and 1999. The prototype could be finished by the turn of the century. Development work carried out through the European Space Agency (ESA) could begin as early as 2004. For the first phase, which will run to the end of 1992, the West German Research Ministry is providing $122 million, 7 percent of its total budget for space activities. The German Aerospace Research establishment is contributing $48 million, and the German Research Society $17 million. A further $22 million is being invested by the West German aeronautics and space industry for a total initial commitment of $209 million.[21]

Figure 4-8--Federal Republic of Germany Saenger II



SOURCE: Messer schmitt-Bolkow-Blohm GmbH, Space *Systems Group.*

United Kingdom Hotol

As early as 1978, British Aerospace Corp. began studying the prospects for lowering the cost of satellite launchings by 80 percent. Out of these studies, and revolving around a new engine proposed by Rolls-Royce, British Aerospace drafted plans to develop Hotol, a fully recoverable and reusable unpiloted launcher capable of taking off and landing from a runway and reaching orbit with a single stage (figure 4-9).

The heart of the project is Hotol's propulsive power, the still-secret Rolls-Royce RB-545, called the Swallow engine. This radically new hybrid rocket engine is designed as a dual-rotor motor, first burning onboard liquid hydrogen while liquefying oxygen as the vehicle moves through the Earth's atmosphere. Above the atmosphere and on into orbit, the engine then uses onboard liquid oxygen to bum the fuel. This engine concept would halve the amount of liquid oxygen required to be carried at takeoff thus dramatically reducing the weight of the craft compared to one using a conventional booster.

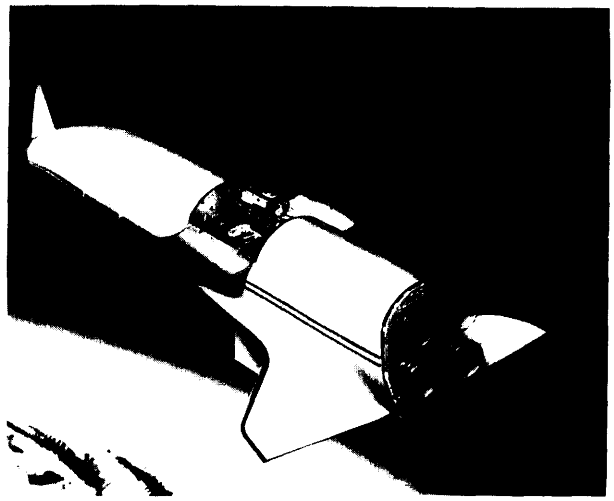
Hotol is designed to reach orbital velocity at a height of 90 km. The craft would then coast into a stable operational orbit of about 300 km. The design goal is to deliver 7 to 11 tons into low-Earth orbit at a cost of $300 per pound. Hotol is designed to operate without human crews aboard for most missions, although a pressurized habitable module could be situated in the payload bay to support astronauts, not as pilots, but in an "executive role."

21 Don Kirk, "Germany Enters Hypersonic Race," Science, vol. 243, Mar. 10, p. 1284, 1989.

Hotol mission scenarios call for the vehicle to launch and recover satellites, service space stations and platforms, conduct microgravity and scientific experiments, and carry out military operations. A fleet of 5 vehicles was planned, each with a 120-mission design life. Hotol's recurring launch cost was estimated at just $5 million.

Hotol design teams completed a 2-year, $4 million proof-of-concept study in late 1987. They outlined a follow-on "enabling technology" program that would lead to a development start in 1994 and a first flight by Hotol near the year 2000. Despite the momentum built up by British Aerospace and Rolls-Royce, the U.K. Government, in July 1988, refused to provide a requested $9 million per year for 3 years to continue Hotol's research and development. The two firms were to match the government funding made available through the British National Space Centre. Hotol's future may depend on international participation but this would require declassification of the Swallow engine, something that the British have been loath to do.

Figure 4-9-United Kingdom Hotol



SOURCE: British Aerospace.