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Shuttle 11 Progress Report

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ABSTRACT

This paper presents a status report on the study of a next-generation manned launch system, or Shuttle II, being conducted at the NASA Langley Research Center. Underlying reasons for considering such a system, including the need for low-cost, safe, and reliable manned access to space, are discussed. System and operational characteristics for such a future vehicle are presented. Several rocket vehicle conceptual designs are depicted that satisfy the stated requirements. The role of advancing technologies is shown to have a major impact on the choice of a vehicle concept. For a near-term technology level, a two-stage rocket vehicle has been selected for in-depth Shuttle II studies. The need for fully-reusable launch systems with radically simpler ground and flight operations is stated to be critical in reducing launch costs.

INTRODUCTION

The Space Shuttle represents a major advancement in the space transportation capabilities of the United States. Despite the Challenger accident, the Space Shuttle has, over many missions, demonstrated itself to be a highly versatile vehicle for both planned and unplanned mission activities. However, one original goal of the Space Shuttle system has remained elusive--that of low-cost space transportation. Because of budgetary pressures in the development phase, early fully-reusable Shuttle concepts evolved into the more labor-intensive partially reusable system actually produced. As a result, recurring hardware and operations costs have proven far higher than expected.

Recent civilian and military space launch requirements studies (ref. 1,2) and the report of the National Commission on Space (ref. 3) have presented exciting and ambitious options for expanding man's activities into the space frontiers over the next several decades. Included in these forecasts are manned geosynchronous Earth orbit (GEO) missions, lunar and Mars bases, and deployment of large Strategic Defense Initiative (SDI) systems. Attaining such goals will require that space transportation costs drop to levels far below those of the present Space Shuttle system or expendable launch vehicles. Otherwise, mission planners will be faced with scaling back activities to stay within anticipated budget constraints.

Routine, low-cost access to space is a compelling enough reason for considering a next-generation space transportation system. But it is not the only one. Projected demands for Space Shuttle launch services will impose maximum allowable flight rates on the system. Sometime in the post-2000 era, individual Shuttle vehicles will face wearout and retirement. The dramatic technological progress which has occurred in many areas since the development and deployment of the Space Shuttle suggests that a new, more efficient space transportation system replace the current system. International competition is also growing in the marketplace in response to rising launch demands, with many new transportation systems under study or development by the Europeans, Japanese, Chinese, and Soviets. Pressures are building on the U.S. to face this market competition with its own launch systems.

The Langley Research Center has for many years been actively involved in examining new space transportation system concepts to fulfill a variety of anticipated mission needs (ref. 4, 5). Early in 1985, Langley was asked by NASA Headquarters to initiate preliminary conceptual studies of a next-generation launch system called "Shuttle II". Early study phases were aimed at defining desired system and operational characteristics of a Shuttle II system. A main objective of the Shuttle II program is to demonstrate vehicle concepts that (a) substantially reduce the cost of space transportation and (b) provide a complement to a transportation architecture that supports a wide range of scientific, defense, and commercial uses. Progress reports on this study have appeared earlier in references 6 and 7.

MISSIONS AND TRANSPORTATION ARCHITECTURE

Planning for a next-generation space transportation system requires detailed views of anticipated future space activities. Mission models for the period 1992-2010 are available (ref. 1,2) for such purposes. Generally, anticipated missions tend to fall within two categories. On one hand there is a need to move large masses--bulk cargo, propellants, large military and civilian satellites--to orbit at the lowest possible cost or "low dollars per pound". But for priority or sortie types of missions involving personnel transport, servicing and repair visits, and movement to orbit and return of high-valued commercial products and supplies. a low "dollars per flight" approach is a valid consideration.

As Figure 1 shows, the Space Shuttle was designed to perform all these space transportation functions. The Challenger accident placed new emphasis on assured access to space with complementary launch systems emerging such as the Air Force Titan 4 among other expendables. In the future, however, a mixed-fleet approach will divide these functions in a more cost-efficient manner. A Shuttle II vehicle would fly the priority/ sortie missions. Near-term technology dictates an all-rocket system, but given time and technology funding, an air-breathing system, such as the National Aero-Space Plane, may emerge as a Shuttle II option. The Langley Shuttle II study is limited to vertical takeoff rocket systems. The heavy-lift functions may be fulfilled initially through the use of a Shuttle-Derived Vehicle (SDV) using many of the same components, facilities, and manpower of the present Space Shuttle system. Later, more cost-efficient partially-reusable or fully-reusable launch vehicles may be phased in to meet anticipated increased launch demands.

Total life-cycle costs (the sum of development, production, and recurring costs) for these systems will, no doubt, greatly influence the timing and appearance of the particular mixed-fleet systems developed. To lower total life-cycle costs, the two vehicles may share common launch sites, operational facilities, and manpower. And in the "common element" approach to vehicle architecture, major launch components may also be shared between vehicles as indicated by the dashed line connecting the mixed-fleet approaches in Figure 1. An example is a first-stage booster used in conjunction with either a manned orbiter element or an unmanned heavy-lift stage.

The present study has placed primary Shuttle II mission emphasis into the three major categories as shown in Figure 2. The personnel transport role assumes ever-increasing emphasis as the Space Station begins operations and undergoes growth. On-orbit servicing is another major role undertaken by Shuttle II. Not only will there be a Space Station in orbit, there will also be many unmanned space platforms and observatories which will require periodic maintenance and repair--a task well-suited for a manned launch vehicle. Space Shuttle crews have aptly demonstrated these tasks in earlier missions. In many mixed-fleet approaches, the heavy-lift vehicle functions only to take payloads to orbit. But there is also a need to bring much of this payload mass back from orbit. This is especially true of high-valued products manufactured in orbit--for example, pharmaceuticals and crystals--as well as Space Station logistics modules and materials. A manned Shuttle II also fulfills this role.

While the payload requirements of a Shuttle II system have not been set, certain "driver" or baseline missions are being used in this study. These include 20,000 pounds to a Space Station operations orbit (262 nautical miles, 28.5 degrees inclination), and 12,000 pounds to a low sun-synchronous orbit (150 nautical miles, 98.0 degrees inclination) for servicing of unmanned polar platforms. The baseline payload bay size is a 15-foot diameter cylindrical volume 30-feet in length. It should be emphasized that these are only representative study missions. The Shuttle II study is examining vehicle design sensitivity to reference mission payloads ranging from 2,500 to 65,000 pounds.

SYSTEM AND OPERATIONS REQUIREMENTS

Understanding the costs of the Space Shuttle system is a key consideration in evaluating design options for a replacement system. Figure 3 examines one aspect--the costs associated with flying Shuttle missions.

Presently, large costs are incurred in both the manpower for ground, flight, and management operations and the replacement and refurbishment of Shuttle hardware. Propellant costs for each flight are a relatively small percentage of the total.

In the future, the need is to reduce launch costs by a large factor--some say an order-of-magnitude reduction. The costs of propellants for a vertical-takeoff rocket system will not change very much. What this implies is the need for a radically new approach to operations concepts, making all Shuttle II system components fully reusable, and flying the vehicle frequently to amortize the facility and manpower costs. These are very difficult objectives. In our study we have sought to define desired operational and vehicle characteristics which would lead us closer to the goal of major cost reductions.

Briefly, we foresee a vehicle which need not have all the capabilities of the present Space Shuttle. Crew size for Shuttle II would be limited--two to five depending on mission type. Maximum duration would be shortened to three days, but the Shuttle II vehicle would operate frequently (fly every two weeks) with a minimum of maintenance and checkout requirements between flights and operate under adverse weather conditions--rain and moderate winds included. Safety is a major concern. The Shuttle II vehicle will possess large performance margins, fault-tolerant subsystems, and abort capabilities. For example, the vehicle will be able to reach orbit even if one engine were to fail at liftoff. Under worst-case conditions, where vehicle recovery was not possible, the Shuttle II would have an escape system to permit crew survival.

Innovative design and improved technologies are needed to reduce the operations labor force. Major assembly and processing would be conducted horizontally in low-bay work facilities. Vehicle/payload integration is an area which, in particular, lends itself to significant processing streamlining. Under present Space Shuttle procedures, an orbiter will sit in a processing facility while the entire cargo bay is reconfigured, interface tests run, and orbiter software changed and verified for each new mission. The Shuttle II concept decouples the vehicle and payload processing and minimizes the interface requirements as depicted in figure 4. Payload containment structures may be standardized for major mission types thus eliminating the need for major reconfiguration after each flight. Installation of the container on a vehicle would take place in the processing facility with only minimum payload access availability at the launch pad. The use of tip fins on the vehicle wing eliminates the need for a large vertical tail and frees fuselage area for the payload canister concept.

The vehicle should also possess an automated,self-diagnostic checkout system with built-in test equipment and modularized subsytems for easy maintenance to speed processing between flights. And, by making the vehicle as autonomous as possible with extensive use of standardized flight software, robotics, and artificial intelligence, many functions of a labor-intensive mission control can be eliminated.

An analogy frequently drawn is that of launch vehicle operations similar in scope to airline operations whereby a small ground crew services and readies an airliner for the next flight, which is then flown in nearly an autonomous mode by a small flight crew. Launch vehicles, however, have not yet reached a state of maturity where such routineness is likely even in a next-generation system. Lessons learned from Space Shuttle operations, however, certainly point the way to changes in design and operations that would provide a closer realization of that goal.

TECHNOLOGY ISSUES

The role of technological advancements in understanding directions for future launch systems is a critical issue. Figure 5 demonstrates how the gross lift-off weight of single- and two-stage vertical-takeoff rocket systems decrease with advancing technologies. The technology level parameter represents a percentage overall dry weight reduction from the Space Shuttle prior to vehicle resizing. Our baseline Shuttle II study considers a vehicle development cycle initiated in the year 1992 by which time all required technologies would need to be in place. This is at about the 25% dry weight reduction level. Highly advanced technologies, predicted for the National Aero-Space Plane, will require more intensive study to make them a reality. They are indicated as a 60% overall dry weight reduction over the Space Shuttle reference.

The figure demonstrates that single-stage-to-orbit (SSTO) rocket vehicles become attractive only when the technology level achieves the equivalent of 30% - 40% dry weight reductions. Thus the defined near-term technology (1992) level suggests a two-stage rocket vehicle as the concept of choice. The outlook for single-stage rocket vehicles improves dramatically at advanced technology levels with the overall lift-off weights of both the single- and two-stage rocket vehicles under a million pounds. Operational considerations would then likely dictate the selection of the single-stage system.

Vehicle dry weight is more closely aligned with overall development and production costs. In figure 6, near-term technology levels suggest selection of a two-stage rocket system. The logistics of moving a Shuttle II vehicle about is an important factor in the selection process. Considering the air-ferry weight-carrying capabilities of a 747 transport aircraft, it is evident that both elements of a 1992-technology two-stage system are ferryable, whereas the dry weight of the SSTO makes its ferry capability prohibitive.

VEHICLE CONCEPTS

Figure 7 provides a size comparison of the present Space Shuttle with the design concepts considered in the Shuttle II study. The single-stage-to-orbit concept using near-term technology is longer than the current Shuttle and weighs more. For polar missions, an augmentation stage must be added. The two-stage vehicle, again employing near-term technologies, is significantly smaller and lighter. Baselined to perform the polar mission, it can carry 30,000 pounds to Space Station orbit. Most dramatic is the effect of applying advanced technology, as contemplated for National Aero-Space Plane use, to rocket vehicles. The SSTO rocket system is dramatically reduced in size and weight.

Because of the large size and weight differences between the SSTO and two-stage concepts at a 1992 level of technology, the two-stage rocket system has been selected for further in-depth studies. Figure 8 is a multi-view of this vehicle. Figure 9 shows views of the orbiter and booster.

The Shuttle II two-stage concept uses dual-fuel, parallel-burn propulsion. At lift-off all engines on the booster and orbiter are running. The unmanned booster is powered by six liquid oxygen-hydrocarbon (RP) fuel engines rated at 250,000 pounds sea-level thrust. The booster has three propellant tanks (liquid hydrogen, liquid oxygen, RP fuel). Hydrogen and oxygen propellants are crossfed to the orbiter stage during the boost phase. Staging occurs at Mach 3 with the booster gliding back to the launch site. The low staging Mach number ensures no special booster thermal protection system requirements and allows significant performance and operations margins to be added without major system weight increases.

The Shuttle II orbiter is propelled by five liquid oxygen-liquid hydrogen engines of 300,000 pounds sea-level thrust each. These engines are based, in part, on the Space Shuttle Main Engine. Most of the orbiter body volume is occupied by the hydrogen and oxygen propellant tanks. At Mach 3 staging, these tanks are still full because of the crossfeed of propellants from the booster.

Unlike the Space Shuttle, the orbiter concept uses a linearized crew module arrangement along the top of the fuel tanks. The forward flight compartment, with a crew complement of up to 5, is positioned such as to allow it to be rocketed free in an emergency escape. Behind the flight compartment is a work/sleep station comparable to the mid-deck of the Space Shuttle. An internal tunnel, covered by a fuselage fairing, connects the crew module to the payload containment structure. Many subsystems are located, for easy access, in the forward nose area and spine fairing.

As the orbiter accelerates towards orbital speed, three of the main engines are throttled down and then switched off. Extendable nozzles on two of the engines are deployed to maximize engine thrust efficiency.

Figure 10 depicts the general operational scenario for this vehicle. Following a mission, servicing of the vehicle would be conducted horizontally in a low-bay facility. Booster, orbiter, and payload container would be processed in separate areas and brought together for vehicle integration. The vehicle's unfueled weight is small enough to permit horizontal towing to the launch pad. A nominal ground turnaround time of ten days is an operational goal for this concept.

At the launch pad, the vehicle is raised to the vertical with a strongback system, fueled and launched. Pad time is reduced to 24 hours or less by dictating that nearly all vehicle preparatory functions occur in the processing facility. Only minimum vehicle maintenance or late payload access functions would be available at the launch pad. Because of highly volatile weather considerations, a rolling enclosure is provided for the time the vehicle is on the launch pad.

TECHNOLOGY REQUIREMENTS

Certain critical technologies have been identified as requiring development before a next-generation vehicle enters its development cycle. Lightweight primary structures, both in material properties and methods of construction, are a driving factor in reducing the size of the vehicle. Space Shuttle experience suggests a Shuttle II vehicle have a thermal protection system (TPS) that is durable, waterproof, and significantly less labor-intensive. This would allow flight even in adverse weather. Reusable, cryogenic propellant tankage is an enabling technology for these concepts. In our studies, the tankage is integral and subject to major loadings. Yet these tanks must function for tens, perhaps hundreds of uses. Inspection procedures for demonstrating tank integrity are also critical.

Reusable hydrocarbon and advanced hydrogen propulsion require technological development. In the area of operations, vehicle technologies related to the use of expert systems, robotics and artificial intelligence would decouple the vehicle from a majority of mission control functions, thus making it autonomous. Fault-tolerant and self-test systems are required to maintain the vehicle.

PHASED APPROACH

The Shuttle II concept shown would begin operations in the post-2000 time period. A phased approach is being considered for this system which could also provide a heavy-lift cargo function. In such a scenario, the Shuttle II booster and an unmanned parallel second stage are developed and flight tested by the late 1990's. The booster, as a consequence of the low staging Mach number, can initially be produced with large design margins, particularly in the area of reusable cryogenic tankage. Estimates are that a second stage, using hydrogen propulsion with crossfeed from the booster, could deliver 75,000 to 100,000 pounds to orbit. Initially the second stage might be entirely expendable, but later the propulsion and avionics package may be recovered from orbit for reuse.

In the post-2000 time period, the manned orbiter stage would be phased in having benefited from several years' experience with similar unmanned systems. During the phase-in period of the Shuttle II system, the present Space Shuttle would continue to fulfill its transportation role, especially with regard to man-critical missions.

SUMMARY

In summary, a manned Shuttle II vehicle will form part of a future mixed-fleet transportation system. To achieve low costs, a fully-reusable system with much simpler operations than the current Shuttle will be necessary. This requires innovative design concepts and operations strategies. A two-stage rocket vehicle is the most likely candidate for a near-term Shuttle II development program. As various rocket-vehicle technologies advance, we see the emergence of single-stage-to-orbit vehicles. Very advanced technologies, as exemplified in the National Aero-Space Plane, will also dramatically improve the performance and operations of rocket vehicles. A number of critical technologies require funding now to ensure they are available when Shuttle II development begins.

Current Shuttle II study efforts are refining the two-stage baseline design concept and defining a detailed operations scenario and cost estimate. This baseline concept will also form the basis of studies examining a mixed-fleet architecture approach to space transportation.

ACKNOWLEDGEMENTS

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SPACE TRANSPORTATION ARCHITECTURE

OPTIONS

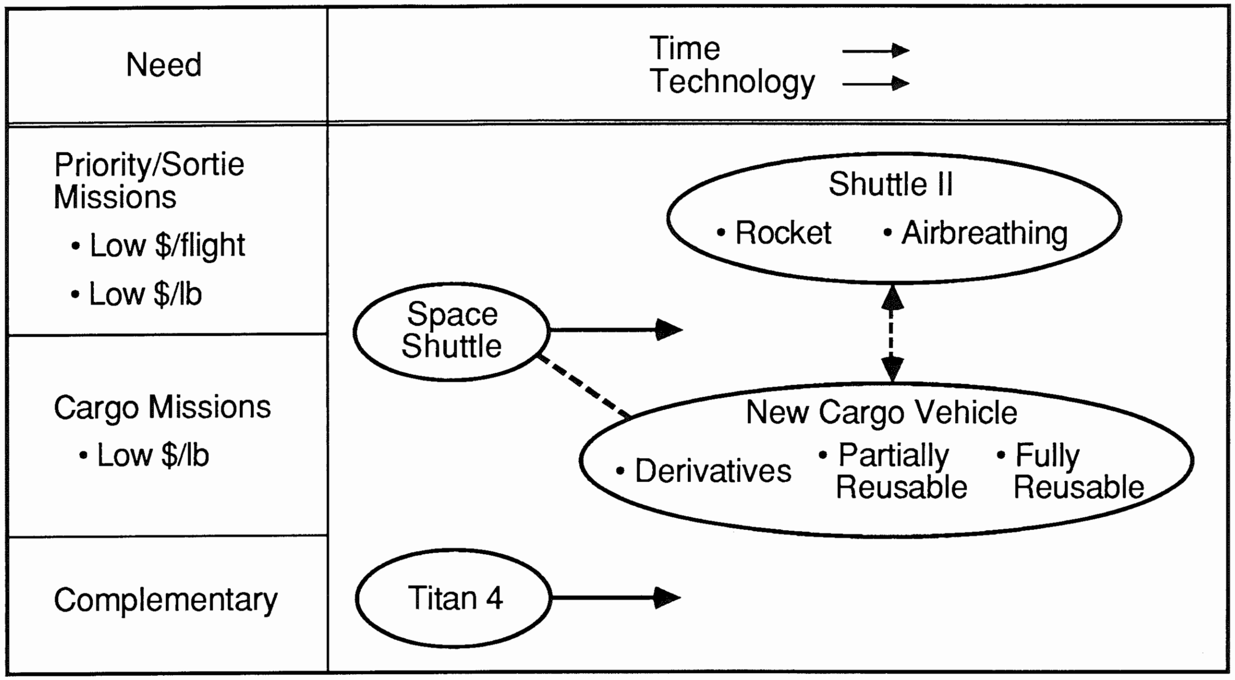


Figure 1.- Space transportation architecture options based on mission requirements.

SHUTTLE II MISSIONS

- People transport
  - Manned access to space station
  - Man-critical missions
  - Rescue
  - Manned exploration
  - Public access to space

- Servicing
  - Space station
  - Co-orbiting platforms
  - Polar platforms
  - Commercial platforms
  - Observatories
  - Other

- Launch and recovery
  - Small payloads
  - Commercial products return to Earth
  - Other down payloads

Figure 2.- Priority/sortie missions for a Shuttle II vehicle.

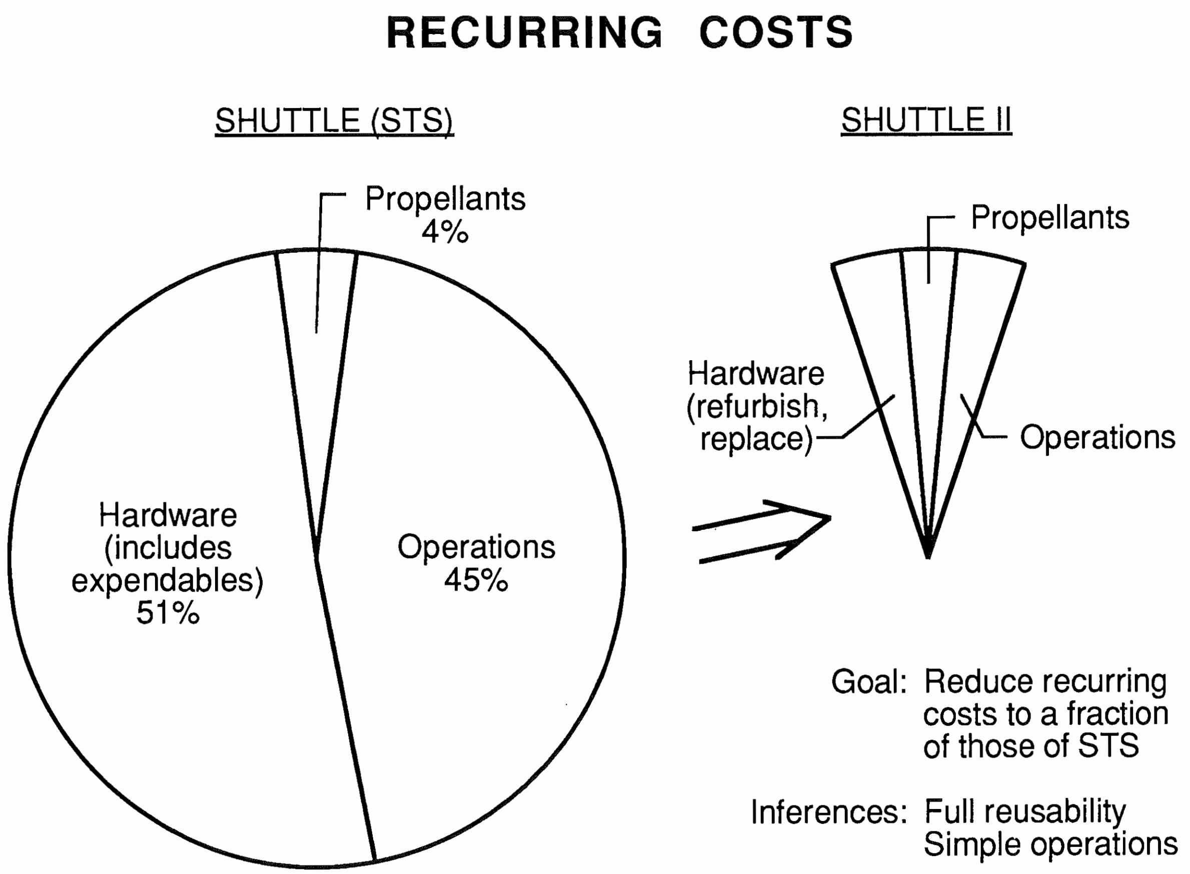
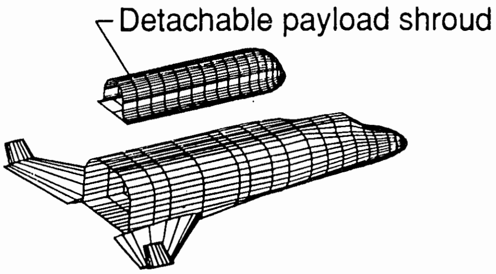


Figure 3.- Reducing recurring costs of flying Shuttle missions.

DETACHABLE PAYLOAD CONTAINER SYSTEM



- Offline processing
- Standardized payload interfaces
- Specialized container systems for dominant mission types
- User access until installation at launch pad

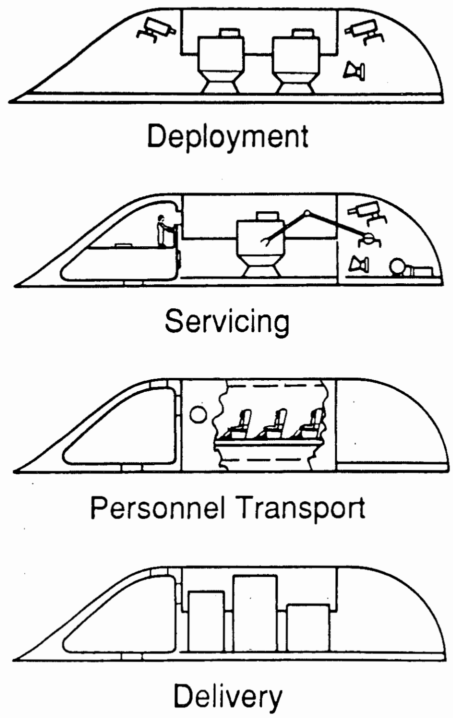


Figure 4.- Containerized payload concept for streamlining ground operations.

TECHNOLOGY EFFECTS ON VERTICAL TAKE-OFF ROCKET VEHICLES

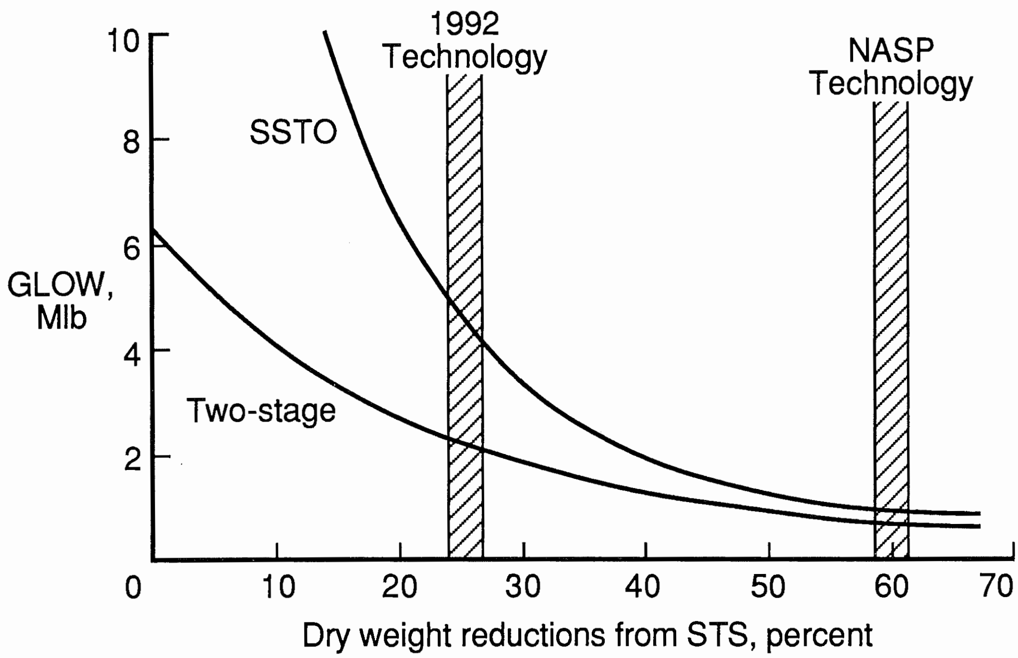


Figure 5.- Effects of technology advancements on gross lift-off weight (GLOW) of rocket vehicles.

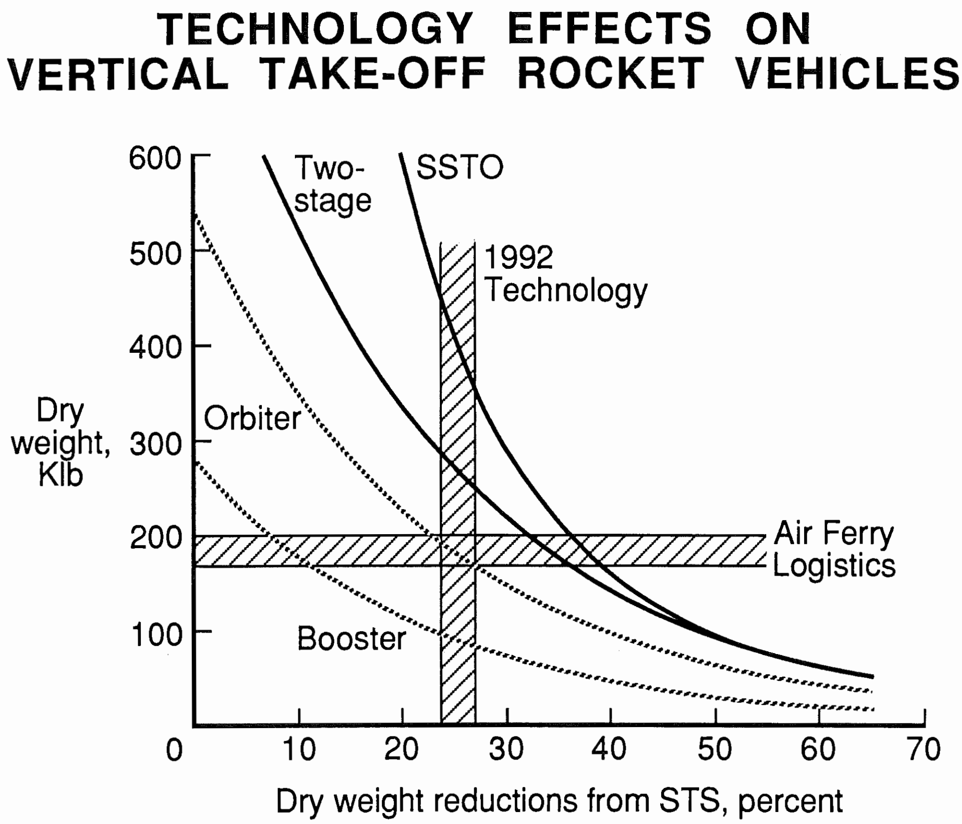


Figure 6.- Effects of technology advancements on dry weights of rocket vehicles.

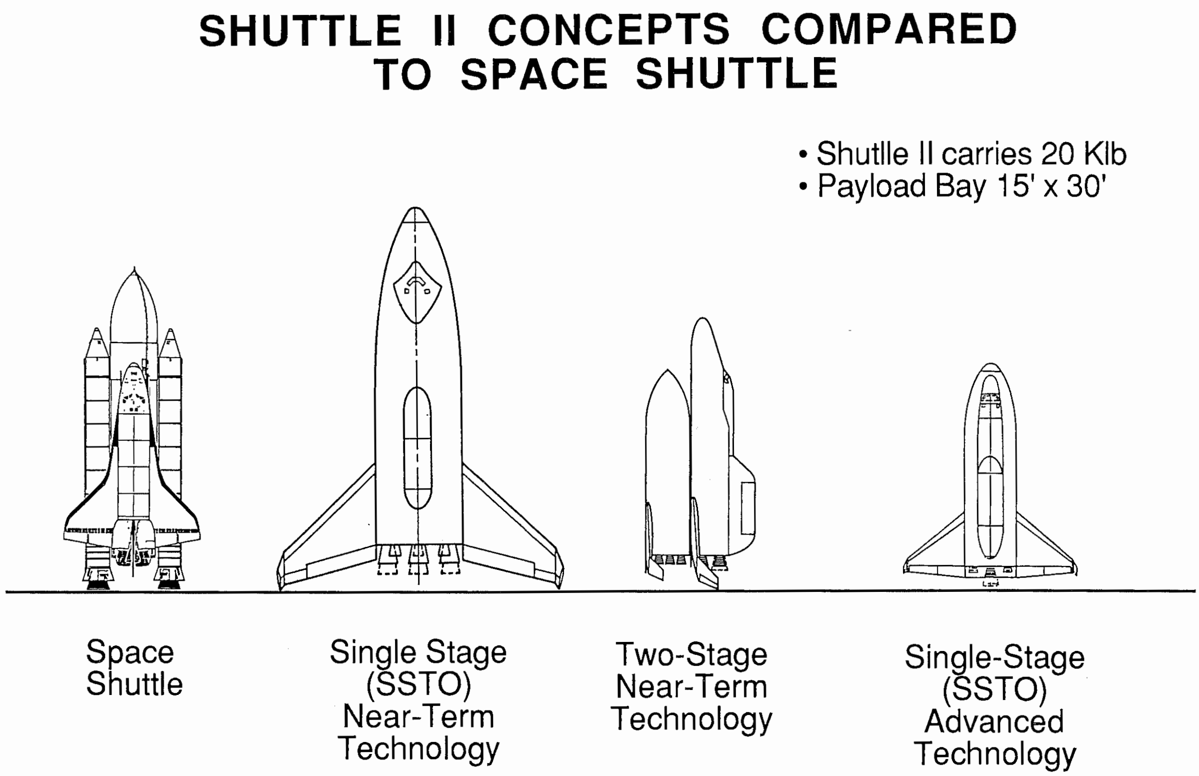


Figure 7.- Several Shuttle II design concepts compared to the Space Shuttle.

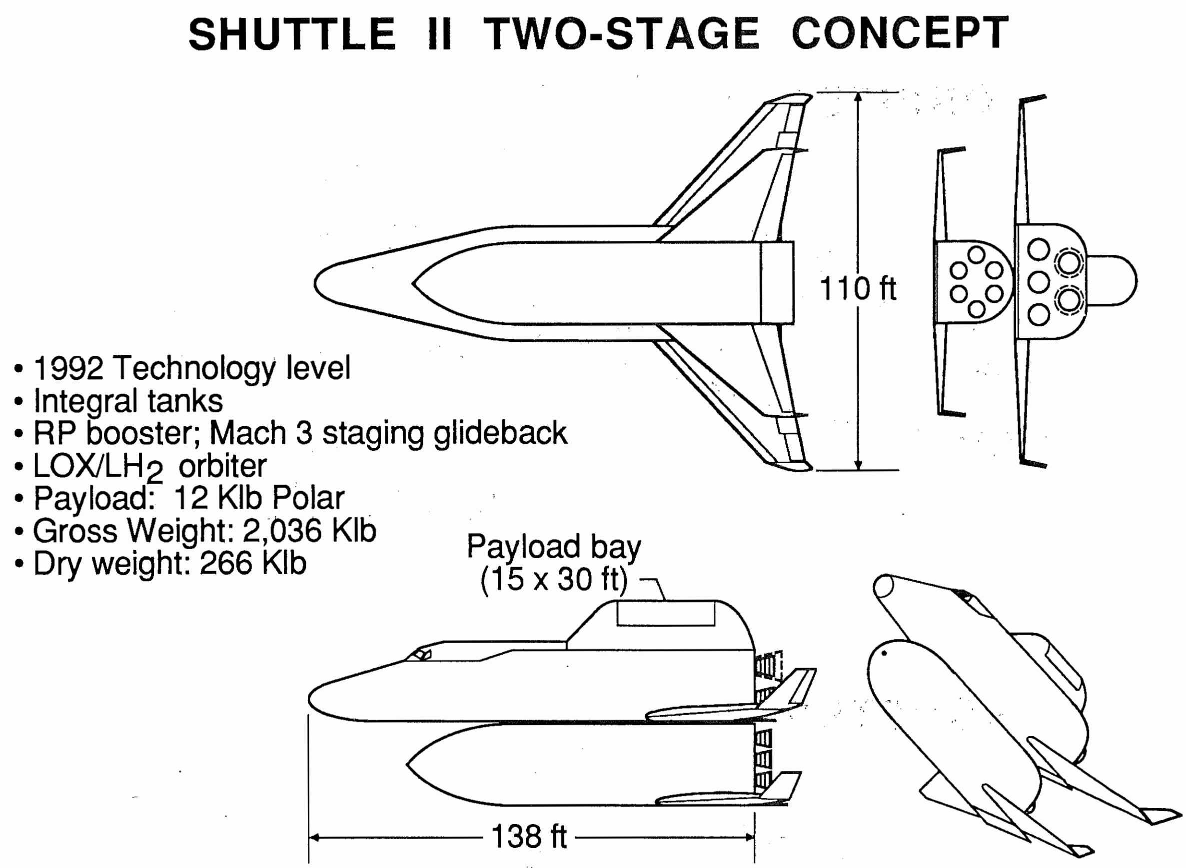


Figure 8.- The Shuttle II baseline two-stage rocket vehicle.

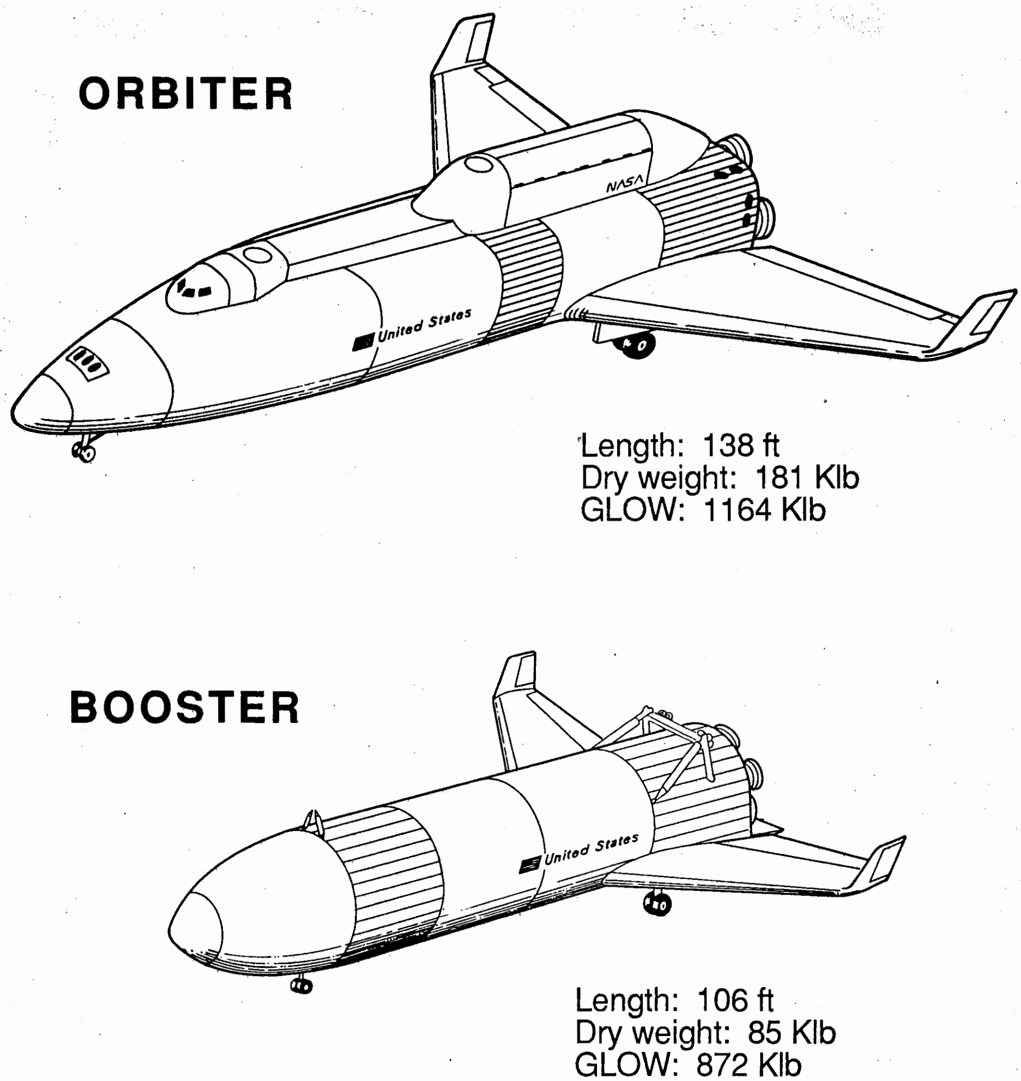


Figure 9.- Views of the Shuttle II orbiter and booster.

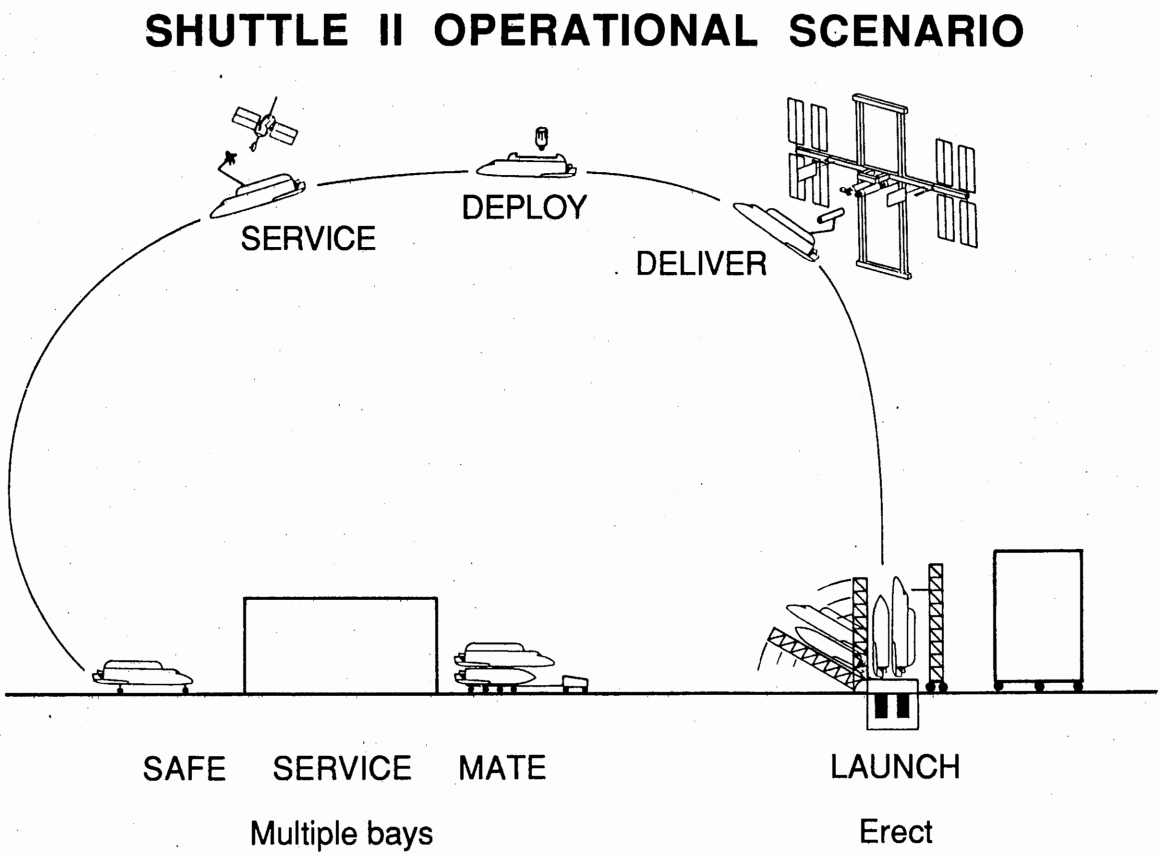


Figure 10.- General operational scenario for a Shuttle II vehicle.