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Apr 25th, 2:00 PM

Paper Session I-A - Advanced Manned Launch System (AMLS) Review

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ADVANCED MANNED LAUNCH SYSTEM (AMLS) REVIEW

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ABSTRACT

A status report on advanced manned launch system (AMLS) conceptual studies being conducted at the NASA Langley Research Center is presented. The primary goal of these studies is identifying means for lowering the cost of manned access to space while fulfilling mission needs. Attention is focused on partial, and fully reusable launch concepts that employ an operations-oriented design approach. Identified in particular are vehicle systems, technologies, and operations factors which influence launch costs, mission success, and safety.

INTRODUCTION

The Langley Research Center has for many years been actively involved in examining space transportation concepts to fulfill a variety of anticipated mission needs (refs. 1 and 2). Since early 1985, Langley has been engaged in preliminary conceptual studies of a next-generation manned launch system called "Shuttle II" (refs. 3, 4, and 5). Early study phases have focused on defining technology levels, systems, and operational requirements for Shuttle II. The objectives have been to define vehicle concepts that (a) substantially reduce the cost of manned space transportation and (b) provide a complement to a transportation architecture to support a wide range of scientific, military, and commercial uses.

Recently, the Shuttle II effort was made part of a larger NASA Headquarters study to define options for next manned space transportation system. As Figure 1 shows, the goals of this broader effort are to define systems that meet required mission needs in terms of personnel transport and manned-presence-required payloads, improved cost effectiveness, increased vehicle reliability, and large operational margins. The NASA multi-center study is examining three approaches to satisfying future manned launch needs. One approach is the evolution of the present Space Shuttle via subsystem and block changes. Another is the definition of a small, personnel launch system (PLS) for carrying people and small amounts of cargo to and from space. A third approach is that of an all-new vehicle to replace the present Space Shuttle when it reaches retirement age. This advanced manned launch system (AMLS) option, sometimes referred to as "clean-sheet" approach, is a continuation of the Shuttle II studies referred to earlier. The purpose of this report is to present a status report on AMLS studies including a number of the vehicle options under consideration.

MISSION NEEDS AND TECHNOLOGIES

A statement of mission needs is a necessary prerequisite to determining future launch system requirements. Future space transportation functions are anticipated to be divided into manned and unmanned categories. Heavy-lift and commercially developed vehicles will carry the burden of cost-effective launch of unmanned payloads. Manned missions will include personnel transport, servicing and repair visits, and movement to orbit and return of high-value commercial products and supplies. Specific mission needs will encompass current mission models, such as the Civil Needs Data Base and military space launch requirements, as well as new initiatives such as lunar and Mars exploration missions and establishment of bases.

Attaining greatly increased levels of space mission activities will require that space launch costs drop significantly below those currently experienced when flying the Space Shuttle or unmanned expendable launch vehicles. Presently, large costs are incurred in both the manpower for ground, flight, and management operations and the replacement and refurbishment of Space Shuttle hardware. Several areas of improvement suggest means for lowering these costs. These include more operationally efficient vehicle subsystems and procedures, greater vehicle reusability, and higher vehicle flight rates to amortize facility and manpower costs.

Figure 2 demonstrates the philosophy of design for AMLS vehicle concepts which recognizes expected mission needs, builds upon lessons learned from operating the Space Shuttle, and exploits new technologies developed since the Space Shuttle was designed. For the present AMLS analyses, two representative missions were selected to allow direct comparison of vehicle concepts on an equal basis -- 20,000 pounds delivered to a Space Station orbit and 12,000 pounds to a low polar servicing orbit (150 nautical miles, 98 degrees inclination). This represents a payload capability less than half that of the Space Shuttle. The crew size is also reduced from the Space Shuttle to a maximum of 5 with a maximum mission duration of 5 days. Chosen for an AMLS baseline is a vehicle development cycle initiated in 1992, by which time all required technologies are assumed to be available. Normal-growth (evolutionary) technology advancements in vehicle structural, propulsion, and subsystem disciplines are assumed rather than any revolutionary breakthroughs in these areas. Many of the aluminum structures of the Space Shuttle are replaced by composite and honeycomb primary structures that are both lightweight and able to endure significantly higher temperatures. Reusable, cryogenic propellant tanks are an enabling technology for those AMLS concepts where vehicle reusability is desired. Subjected to major loadings, these aluminum-based propellant tanks must function for tens, perhaps hundreds of uses. Critical also are inspection procedures for demonstrating tank integrity which are not labor intensive. Space Shuttle experience suggests an AMLS thermal protection system (TPS) that is durable, waterproof, and significantly less labor intensive for reduced operations costs.

For primary propulsion, low-cost reusable rocket engines are needed. Technology and design studies of such engines have been studied at NASA Marshall Space Flight Center in the Space Transportation Booster Engine (STBE) and Space Transportation Main Engine (STME) studies. Low-cost, operationally efficient Space Shuttle Main Engine (SSME) designs are also under consideration and present an option for future manned launch systems.

On the subsystems level, several key technologies contribute to reductions in operational requirements and improved maintainability. Hydraulics are replaced with all-electric systems employing electromechanical actuators for both engine gimbal and flight controls. Hypergolic propellants in orbital maneuvering and reaction control systems (OMS and RCS) are replaced by nontoxic, cryogenic, hydrogen-oxygen systems. Advanced avionics are lighter, yet more powerful in function and can help decouple the vehicle from a majority of ground-based mission control functions, thus introducing a significantly higher level of autonomy.

DESIGN FOR OPERATIONS AND RELIABILITY

Rocket systems designs of the past have generally been characterized as "performance-driven" because of restricted development budgets or the desire to maximize payload to orbit. This has often penalized the operational characteristics of such systems with increased launch costs as a consequence. Figure 3 shows a "design-for-operations" approach where due consideration is paid to the effects of vehicle design on recurring

costs from the outset of design. Many of the benefits of reduced payload class and advanced technologies mentioned above contribute to significant weight savings in new vehicle designs. A portion of this weight savings, however, has been applied to several aspects of vehicle design that enhance the operations, reliability, and safety factors of the system.

In the area of operations, AMLS designs incorporate the containerized concept for payload accommodations to simplify the payload integration process and provide for payload flexibility in mission planning. Concepts, which employ a winged booster, stage at a Mach number of 3 to allow the booster to glide back to the launch site without the need of an additional air-breathing cruise propulsion system or the added heat protection required for higher staging Mach numbers. A 9.4 % system dry weight penalty is the price for achieving this reduced operational complexity. Subsystems which are fault-tolerant and possess built-in test equipment to monitor systems condition contribute to operations streamlining. Subsystem units, where feasible, are of a modular design for easy removal and replacement.

Issues of vehicle reliability and safety have been raised in light of the *Challenger* accident and other launch vehicle failures. Mission success is enhanced by setting as an abort criterion that the vehicle be capable of reaching orbit even if any stage's main engine were forced to safely shut down at liftoff or during flight. Derating engine performance in this manner increases vehicle size and weight by 10.5 % for two-stage fully reusable vehicles over a design not incorporating engine-out performance. In the event safe abort of the vehicle is not possible, all AMLS designs incorporate a crew emergency escape system consisting of abort motors to jettison a crew flight station module in which the crew rides during ascent and descent flight through the atmosphere.

VEHICLE CONCEPTS

The effects of technology levels on vehicle concepts have appeared in previous Shuttle II papers (refs. 1, 4, and 5). An important conclusion of the earlier work has been the determination that single-stage-to-orbit rocket vehicles are not competitive in size and weight with two-stage rocket vehicles for the assumed 1992 technology readiness date and with the operations-oriented design features. Thus, only two-stage concepts have been considered in follow-on AMLS studies as depicted in Figure 4. These concepts include vertical-takeoff rocket vehicles with varying degrees of reusability as well as a horizontal-takeoff concept employing an air-breathing first stage and rocket second stage. All vehicles were sized to the same polar servicing mission and technology levels and incorporate the design-for-operations features discussed previously. Rocket vehicles were examined that had alternative fuels for the booster or first stage. In one, liquid methane (CH₄) and liquid oxygen (LOX) were burned in STBE-type gas-generator engines (with liquid hydrogen (LH) used in the gas generator and also acting as a coolant). Another booster version used all-oxygen and hydrogen propellants burned in the same type STME gas-generator engines as used in the upper stage.

Figure 5 compares the overall system gross and dry weights for the various concepts using either methanol or hydrogen booster propulsion. In general, little dry weight penalty was noted when using hydrogen propulsion for both stages. Similar results using various contractor STBE and STME engines in two-stage manned and heavy-lift vehicles were also reported in reference 6. Significant advantages exist for common propellants and engine types in both stages. Deleting STBE-type engines eliminates development costs of that engine. Increased line production of the hydrogen propellant engine reduces production costs per engine. Operations are simpler as common engine systems are maintained on both stages. Elimination of hydrocarbon fuel also eliminates production, storage, and handling facilities and the associated management organization and manpower. The configurations reported below utilize all-hydrogen propulsion.

Fully Reusable Concept

Figure 6 details the two-stage fully reusable AMLS concept. At liftoff, all engines on both stages are running. The booster stages at Mach 3 to glide back to the launch site. The orbiter uses LOX/LH propellant crossed from the booster during the boost phase and LOX/LH supplied from large integral tanks for the ascent to orbit. Integral, reusable cryogenic propellant tanks are a critical technology issue. While reusable tanks can significantly reduce recurring costs (not having to replace expended hardware such as a

external tank as on the Space Shuttle), the technology means and manpower to inspect such tanks on a regular basis may also be costly and raise mission safety concerns. The containerized payload is carried on the back of the orbiter in an external canister arrangement. Access to the payload canister is through a tunnel leading from the forward crew cabin.

Drop-Tank Concept

Figure 7 depicts the drop-tank version of the fully reusable vehicle. Similar to some Phase B Space Shuttle concepts, most of the hydrogen propellant of the orbiter is housed within twin, expendable external drop tanks. This eliminates a large portion of the tank reuse verification problem. Also, it has the effect of reducing the overall size and weight of the concept, and permits payload canisters to be mounted internally in the fuselage thus eliminating the external canister fairing structure. Crossfeed systems from the booster and from the external tanks to the orbiter engines are more complex, however. Also, there are two more elements, the external tanks, to handle and integrate during ground operations with resulting increased operations costs. The external tanks are carried to orbit and then released. Onboard attitude control and deorbit rocket systems are used for controlled destructive reentry. It has been suggested that these tanks might be used for secondary purposes on orbit. For example, the Space Station has a significant amount of return-to-Earth cargo requirements. Some of this is disposable refuse. One proposed use of these tanks is to load them with such refuse before commanding them to destructive reentries. A more sophisticated use would involve reconfiguring the tank sections into blunt-body reentry shapes to safely land return cargo. Either of these uses must figure in a mission needs statement so that appropriate design allowances are made for the vehicle and tanks during the design process.

Booster-Core-Glider Concept

The booster-core-glider concept, shown in Figure 8, carries removal of propellants from the orbiter a step further and places all LOX/LH propellants in an expendable core stage. This eliminates all tank inspection problems associated with the orbiter vehicle. The crew and payload sit on top in a separable glider stage. Because of the arrangement, the main propulsion is removed from the glider and placed in a recoverable propulsion/avionics (P/A) module at the base of the core stage. As before, a winged glideback booster provides boost and crossfeed of propellants up to the Mach 3 staging point. The payload canister is installed inside the glider fuselage. The glider wing shape is modified to reflect the more forward center-of-gravity position of this design. The system is operationally complex as it involves four elements (booster + core + P/A module + glider) with the P/A module and glider both requiring reentry capabilities.

Expendable-Stages-with-Glider Concept

Lightest in gross and dry weights of the rocket vehicle concepts is the expendable stages-with-glider concept depicted in figure 9. Unlike the previous configurations using a Mach 3 glideback booster, the first stage in this concept is not recovered and has been sized for a Mach 10 optimum staging Mach number. The smaller second stage powers the glider the rest of the way to the orbit injection point and then follows a destructive reentry trajectory. The glider is identical to that used for the booster-core-glider concept. Ground operations are simplified by only having one return element to process. But recurring costs are driven by the replacement requirements of the two expended booster stages.

Air-Breathing/Rocket Concept

Horizontal-takeoff concepts are under active consideration both in the United States and Europe and include advanced single-stage-to-orbit vehicles such as the National Aero-Space Plane (United States) and HOTOL (England), and the Sanger two-stage concept (Germany). For the AMLS studies, a two-stage horizontal-takeoff concept was designed to the same mission scenario and technology level as the all-rocket vehicles. The first stage employs air-turbo-rocket (ATR) propulsion to a Mach 6 staging point, while the rocket second stage uses STME-type engines. A critical design parameter is the minimization of transonic wave drag. This led to the design shown in figure 10. The overall gross weight is the lightest of all the AMLS concepts because of the absence of significant amounts of liquid oxygen not required during the flight to Mach 6. However, as shown in figure 5, the dry weight is the heaviest of all the concepts. Since dry weight is related to DDT&E costs, the inference is that the air-breathing/rocket system would be very costly to develop.

In addition, the ATR engine assumed had a rather optimistic engine thrust/weight ratio of 20, whereas a value of 10 may be more realistic. Whether the ATR engine is representative of 1992 technology is questionable.

DISCUSSION

Figure 11 presents perceived trends in life-cycle costs for vehicle types with varying degrees of reusability. The life-cycle cost-axis intercepts represent the sum of the initial design, development, test and evaluation (DDT&E), and production costs, while the slopes of each line relate to recurring costs of flying each vehicle. Initial costs are directly related to the dry weights and complexity of the vehicles, while recurring costs relate to operations costs, including the number of elements requiring integration and the costs of replacing expendable hardware. Knowledge of the life-cycle launch requirements (total launches for vehicle lifetime) then suggest a vehicle type for lowest overall life-cycle cost. For only a few launches, expendable-stage systems are optimum, but for large numbers of launches, the reusable system is suggested as more cost effective.

Presently, only preliminary estimates of DDT&E, production, and recurring costs are available for the all-rocket concepts. The most interesting result concerns the booster-core-glider concept depicted in figure 11. As expected, recurring costs are higher than for the fully reusable concept as expended core stages must be purchased, more elements integrated during processing, and recovery operations of the P/A module accounted for. Unexpectedly, the initial costs of such a system are higher than for the fully reusable vehicle even though the overall system dry weight is less. This result has been traced to the high cost of the completely recoverable propulsion/avionics module. Refined cost estimates of the AMLS concepts will be used to verify these results and provide quantitative estimates for all the concepts.

SUMMARY

Advanced manned launch systems (AMLS) studies underway at NASA Langley Research Center are part of a broader effort aimed at determining options for the next manned space transportation system. AMLS systems will be required to satisfy mission needs coupled with low-cost space transportation. Exploitation of new technologies results in weight savings which can be returned to the vehicle in the form of robust subsystems, increased reliability, and assured mission success. While requirements and vehicle concepts will continue to evolve in the studies underway, results to date indicate vertical-takeoff rocket vehicles employing all-hydrogen propulsion and high degrees of reusability appear the most cost-effective for high flight rates. Technology developments in the areas of reusable cryogenic tanks, all-hydrogen propulsion, low-maintenance thermal protection systems, electromechanical actuators, and fault-tolerant systems are needed to ensure readiness for the next manned system development.

ACKNOWLEDGEMENTS

This paper summarizes only briefly the work of several of the individuals of the Langley Research Center AMLS study team. The authors would also like to recognize the contributions made by other team members including: W. Douglas Morris (operations), Dr. James A. Martin (propulsion), J. Chris Naftel and Richard Powell (trajectories), Chris Cruz (aerodynamics), Ian MacConochie (materials and subsystems), Joe Rehder (vehicle geometries), Mark Cunningham (air-breathing propulsion studies), Kathryn Wurster (heating), and Dean (costing). These studies are jointly sponsored by the NASA Office of Space Flight and Office of Aeronautics and Space Technology.

- Satisfy people/payload requirements
- Improve cost effectiveness
- Increase reliability
- Increase operational margins

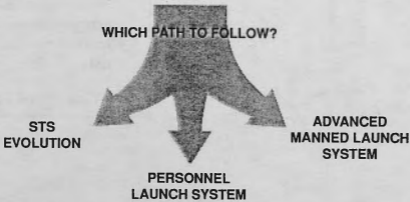


Figure 1. - Options for the next manned space transportation system.

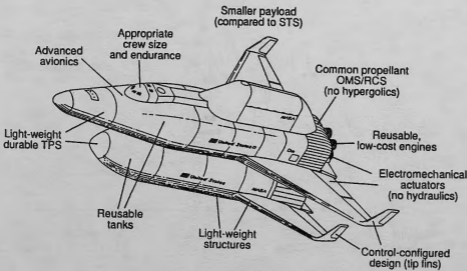
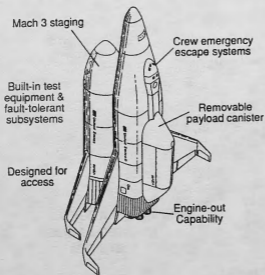


Figure 2. - AMLS design characteristics based on mission needs, lessons learned, and exploitation of new technologies.



**TECHNOLOGY ADVANTAGE
APPLIED TO:**

- Operations streamlining
- Robust subsystems
- Improved reliability
- Assured mission success
- Safety

NOT MAXIMUM PAYLOAD

Figure 3. - Design-for-operations approach for AMLS.

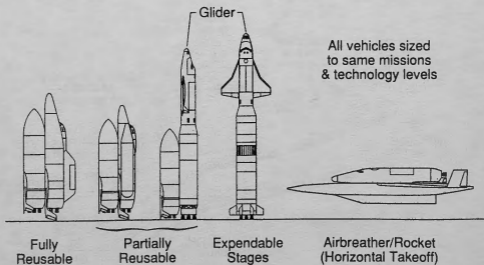


Figure 4. - Advanced manned launch system two-stage concept options.

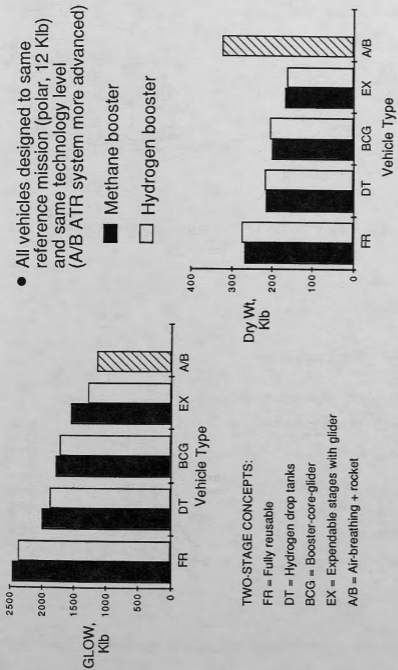


Figure 5. - AMLS vehicle weight comparisons.

- Fully reusable, parallel burn with crossfeed
- Glideback booster, Mach 3 staging
- LOX/LH propellants
- Weights
 - Liftoff -- 2,362 Klb
 - Dry -- 275 Klb
- Overall length -- 141 ft
- External payload canister

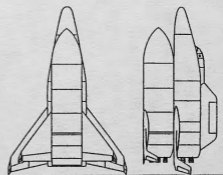


Figure 6. - Fully reusable AMLS two-stage rocket concept.

- Partially reusable, parallel burn with crossfeed
- Expendable hydrogen drop tanks
- Glideback booster, Mach 3 staging
- LOX/LH propellants
- Weights
 - Liftoff -- 1,877 Klb
 - Dry -- 218 Klb
- Overall length -- 126 ft
- Internal payload canister

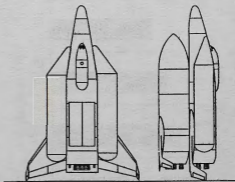


Figure 7. - Partially reusable AMLS concept with hydrogen propellant drop tanks.

- Partially reusable, parallel burn with crossfeed
- Glideback booster, Mach 3 staging
- Expendable core stage; reusable P/A module and glider
- LOX/LH propellants
- Weights
 - Liftoff -- 1,707 Klb
 - Dry -- 204 Klb
- Overall length -- 205 ft
- Internal payload canister

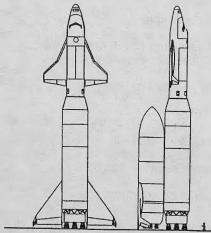


Figure 8. - Partially reusable AMLS concept with expendable core stage.

- Series burn, expendable stages with glider
- Mach 10 booster staging
- LOX/LH propellants
- Weights
 - Liftoff -- 1,279 Klb
 - Dry -- 163 Klb
- Overall length -- 235 ft
- Internal payload canister

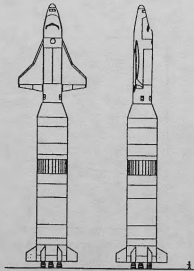


Figure 9. - AMLS concept with expendable stages and manned, reusable glider.

- Fully reusable
- Air-breathing (ATR) first stage, LOX/LH rocket second stage
- Mach 6 staging
- Weights
 - Liftoff -- 1,142 Klb
 - Dry -- 324 Klb
- Overall length -- 228 ft
- Internal payload canister

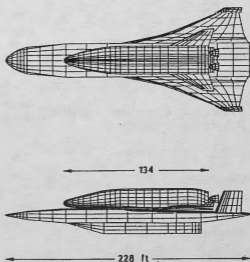


Figure 10. - Horizontal-takeoff AMLS concept with air-breathing first stage and rocket second stage.

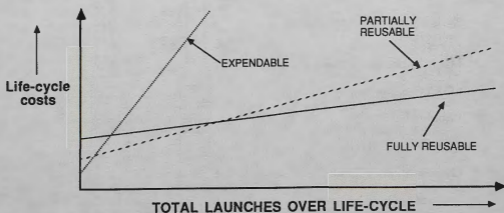


Figure 11. - Effects of vehicle reusability on life-cycle cost trends.

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