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Rocket-Powered Single-Stage Vehicle Configuration Selection and Design

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A reusable rocket-powered, single-stage launch vehicle has been designed as a part of the Advanced Manned Launch System study to examine options for a next-generation manned space transportation system. The configuration selection process used a response surface methodology for multidisciplinary optimization. The methodology was used to determine the minimum dry weight entry vehicle to meet constraints on landing velocity and on subsonic, supersonic, and hypersonic trim and stability. Once the optimum configuration was determined, a multidisciplinary conceptual vehicle design was performed. This paper presents the results of the configuration selection methodology and summarizes the overall conceptual design process with special attention given to the individual disciplines of weights/sizing, structures/materials, configuration, flight mechanics, aerodynamics, aeroheating, propulsion, and operations.

Nomenclature

A_{ref} = reference wing area, ft^2
b = equation coefficient
C_m = pitching moment coefficient
$C_{m\alpha}$ = first derivative of C_m with respect to α
g = acceleration of gravity, 32.2 ft/s^2
L/D = lift/drag
M = Mach number
M_e = Mach number at boundary-layer edge
n = number of configuration variables
q_∞ = dynamic pressure, psia
Re_θ = momentum-thickness Reynolds number
R_n = nose radius, ft
T/W = thrust/weight
V_{land} = landing velocity, kt
x = distance from nose of vehicle, ft
Y = response surface value
y = configuration variable value
α = angle of attack, deg
δ_{bf} = body flap deflection, deg
δ_{elev} = elevon deflection, deg
ΔV = incremental velocity, ft/s

Introduction

A NUMBER of manned Earth-to-orbit (ETO) vehicle options to replace or complement the current Space Transportation System are being examined under the Advanced Manned Launch System (AMLS) study.[1–3] To provide a range of schedule and technology options, a wide variety of vehicle types and propulsion systems have been examined. These include single-stage and two-stage systems, systems using rocket and airbreathing propulsion, systems for personnel and/or cargo transportation, and systems with varying degrees of reusability.[4–6] The AMLS effort is part of a larger study to define systems that meet future mission requirements of transporting personnel and payloads requiring a manned presence, while emphasizing improved cost effectiveness, increased vehicle reliability, and large operational margins. The goals of the AMLS study are to examine systems that provide routine, low-cost manned access to space. Technologies and system approaches are being studied that will contribute to significant reductions in operating costs relative to current systems.[7] The single-stage vehicle presented in this paper would be expected to have a 2005–10 initial operating capability to replace an aging Shuttle fleet. Hence, a 1995–2000 technology readiness date has been assumed to represent normal growth (evolutionary) technology advancements in vehicle structure, propulsion, and subsystems. Although many of these assumed technological advancements contribute to significant weight savings in the vehicle, a portion of this weight savings has been applied to aspects of vehicle design that enhance the operations, reliability, and safety factors of the system.

The introduction of a reusable single-stage vehicle (SSV) into the U.S. launch vehicle fleet early in the next century could greatly reduce ETO launch costs. Currently, the AMLS study is concentrating on the design and evaluation of winged, rocket-powered, single-stage vehicles to transport 20,000 lb of payload and two crew to and from the Space Station Freedom (SSF). Such an SSV could also be used for SSF personnel transport and would eliminate the need to develop, produce, and maintain two dissimilar vehicles as required by two-stage systems. The conceptual design of an SSV using a wide variety of evolutionary technologies has recently been completed. The overall design process is summarized in this paper with special attention given to the individual disciplines of weights/sizing, structures/materials, configuration, flight mechanics, aerodynamics, aeroheating, propulsion, and operations.

In the design of the AMLS SSV, a number of configuration trade studies were performed in an attempt to optimize the reference vehicle with respect to important vehicle parameters like dry weight and operational complexity. This configuration design process used a response surface methodology[8] for multidisciplinary optimization of the SSV entry configuration. The methodology was used to determine the minimum dry weight entry vehicle that met constraints on landing velocity and on subsonic, supersonic, and hypersonic trim and stability. The design and analysis of the AMLS SSV was facilitated by the use of state-of-the-art computer design packages in a variety of disciplines. These tools, and the methods employed in the analysis process, are also summarized as a part of this paper.

Analysis Methods

Conceptual Vehicle Design

The conceptual design of next-generation launch systems requires proper consideration of the effects of trajectory, weights/sizing, ge-

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ometry, aerodynamics, and aeroheating. All of the trajectory analysis for the AMLS single-stage vehicle was performed using the three-degree-of-freedom program to optimize simulated trajectories (POST). POST is a generalized point mass, discrete parameter targeting and optimization program that allows the user to target and optimize point mass trajectories for a powered or unpowered vehicle near an arbitrary rotating, oblate planet.[9] The weights and sizing analysis was performed using the configuration sizing (CONSIZ) weights/sizing package. CONSIZ provides the capability of sizing and estimating weights for a variety of aerospace vehicles using mass-estimating relations based on historical regression, finite element analysis, and technology level. All of the geometry and subsystem packaging of the AMLS SSV was performed using the solid modeling aerospace research tool (SMART) geometry package. SMART is a menu-driven interactive computer program that provides three-dimensional Bezier surface representations of aerospace vehicles for use in aerodynamic and structural analysis.[10] The aerodynamic preliminary analysis system (APAS) was used to determine vehicle aerodynamics. In the subsonic and low supersonic speed regimes, APAS uses a combination of slender-body theory, viscous and wave drag empirical techniques, and source and vortex panel distributions to estimate the vehicle aerodynamics. At high supersonic and hypersonic speeds, a noninterference finite element model of the vehicle is analyzed using empirical impact pressure methods and approximate boundary-layer methods.[11] An aeroheating analysis of the AMLS SSV was also performed using the Miniver aeroheating package. Miniver uses a laminar Blasius skin-friction solution and a turbulent Schultz-Grunow skin-friction method that employs the Eckert reference enthalpy method and a Fay-Riddell method for stagnation-point analysis.[12] Figure 1 demonstrates the iterative process required between these various disciplines to obtain a vehicle point design.

Configuration Optimization

The parametric optimization of the reference AMLS single-stage configuration employs a response surface methodology (RSM) originally developed by Box and Wilson.[8] The RSM utilizes central composite design (CCD) to efficiently characterize a parameter space using statistically selected experiments (or configurations). Central composite design employs orthogonal arrays from design of experiments theory to study a parameter space, which usually has a large number of decision variables, with a significantly small number of experiments (or configurations).[13,14] Reference 15 summarizes an application of first-order Taguchi methods to launch vehicle parametric design and optimization. Central composite design is a second-order extension of these methods. Central composite design utilizes first-order models, augmented by $2n + 1$ additional experiments (where n is the number of parameters to be varied), to allow estimation of the coefficients b of a second-order response surface model of the following type:

$$Y = b_0 + \Sigma b_i y_i + \Sigma b_{ii} y_i^2 + \Sigma\Sigma b_{ij} y_i y_j$$

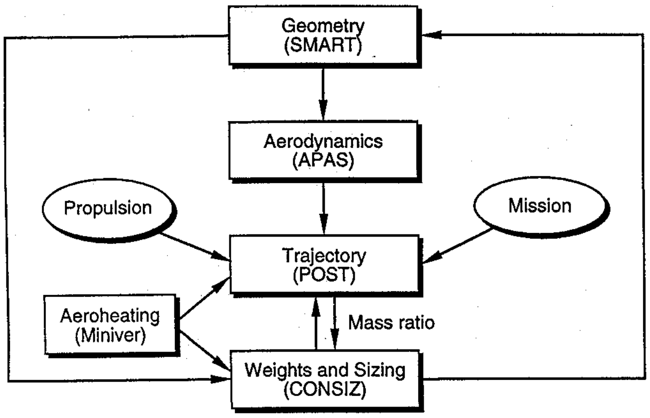

Fig. 1 AMLS vehicle design process.

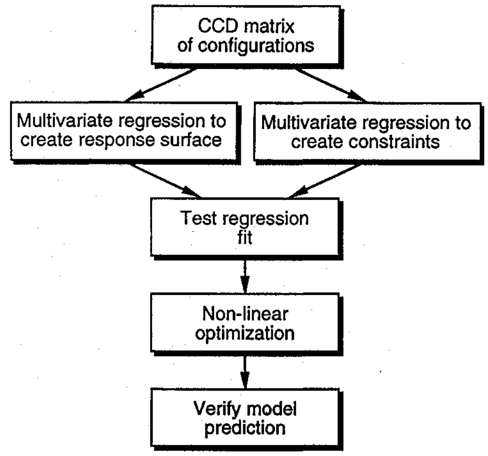

Fig. 2 Response surface methodology.

For this application, Y could be the vehicle weight, and each y could be a vehicle parameter to be varied. Construction of a second-order model requires that each design parameter be varied over at least three levels (or values) to allow estimation of the equation coefficients. A full factorial design process would require 3^n experiments. Reference 15 demonstrates that the required number of experiments can be greatly reduced by employing fractional factorial design methods like those of Taguchi. However, the number of experimental point designs needed for fitting a second-order model using CCD is significantly less than those required by Taguchi's orthogonal arrays or by full factorial designs. For example, a problem involving 5 parameters would require only 27 experiments using CCD, as opposed to 81 required by Taguchi's method and 243 required by a full factorial design study.

The RSM design and optimization method used in the study is shown in Fig. 2. The use of CCD, multivariate regression, and nonlinear optimization techniques form the basis of RSM.[16] The central composite design element is used to efficiently determine the multivariate design parameter combinations needed for analysis. The resulting data are then analyzed using regression analysis techniques to determine the output response surface as a function of the input parameters. The resulting generalized response surface equation is then statistically analyzed for lack of fit. The optimum parameter values are then determined using nonlinear optimization techniques to analyze the second-order response surface. Analytically or statistically determined constraints can be used in this nonlinear optimization process. A verification experiment is then performed to determine the predictive capability of the model. This methodology allows rapid exploration of the parameter space and determination of sensitivities. It also allows easy modification of constraints, without performing additional experiments. The regression and optimization analysis can be performed efficiently using conventional spreadsheet software.

Vehicle Concept

Mission and Guidelines

The design reference mission for the AMLS single-stage vehicle is to deliver to the SSF and return a 20,000-lb payload and two crew when launched from the Eastern Test Range at the Kennedy Space Center (KSC). The vehicle, shown in Fig. 3, is designed to support two crew for a five-day mission duration. Additional personnel (four to six) and consumables could be accommodated in an SSF crew rotation module located in the upper portion of the payload bay. The vehicle is designed to be flown with crew only when necessary and could be flown in an unmanned mode. The payload bay is 15 ft in diameter and 30 ft long. Onboard propellant would provide an incremental velocity (ΔV) of 1100 ft/s following launch insertion into a 50 × 100 n.mi. orbit. Landing would nominally be at the KSC launch site. Examinations of recent mission models of future ETO transportation requirements indicate that a vehicle with these capabilities can capture a very large portion of future civil, military, and commercial payloads.[17–19]

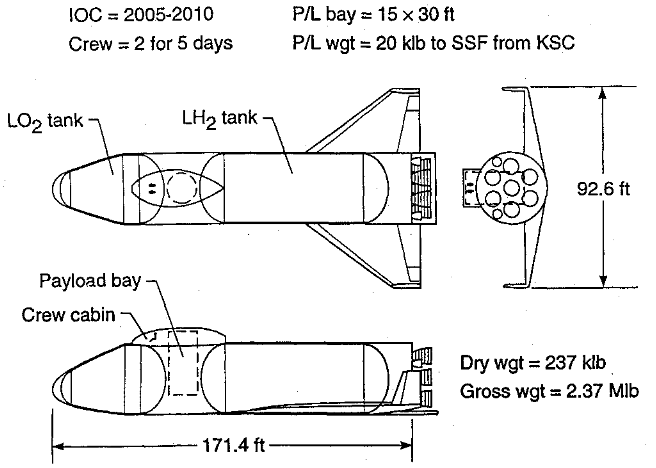

Fig. 3 Reference AMLS SSV configuration.

The SSV was required to have a 1100-n.mi. cross-range capability to allow once-around abort for launch to a polar orbit and to increase daily landing opportunities to selected landing sites. The SSV is also required to have a full range of intact abort opportunities in the event of a forced shutdown of a single main engine. Crew and passenger escape is provided by ejection seats in the appropriate portions of the flight regime. All vehicle trajectories have maximum acceleration limits of 3 g and normal load constraints equivalent to a 2.5-g subsonic pull-up maneuver. In the design of the AMLS SSV, a 15% dry weight growth margin was allocated.

Baseline Vehicle Configuration

The reference vehicle, which resulted from the configuration optimization process described later, is a vertical-takeoff, horizontal-landing winged concept with a circular-cross-section fuselage for structural efficiency. As shown in Fig. 3, the payload bay is located between an aft liquid hydrogen (LH_2) tank and a forward liquid oxygen (LO_2) tank. The normal-boiling-point LH_2 and LO_2 propellants are contained in integral, reusable cryogenic tanks. The vehicle employs wing tip fins for directional control rather than a single vertical tail. The crew cabin is located on top of the vehicle. An airlock/workstation located aft of the crew cabin provides crew access to the payload bay and to the SSF through a hatch on top. The vehicle employs a standardized payload canister concept with common interfaces to allow off-line processing of payloads and rapid payload integration. The liftoff thrust-to-weight ratio (T/W) of the SSV is 1.22. As shown in the figure, the total vehicle dry weight is 230,000 lb, and the gross weight is 2,320,000 lb. Evolutionary propulsion, structure, thermal protection system (TPS), and subsystem technologies are utilized that are consistent with an initial operating capability of 2005–10.

Configuration Selection

Configuration Screening

Initial configuration screening indicated that vehicles with circular-cross-section fuselages held the most promise for obtaining the high propellant mass fractions required to achieve single-stage-to-orbit capability because of their high structural and packaging efficiency. Initial AMLS SSV configurations, like the one described in Ref. 20, utilized an aft LO_2 tank to provide a lighter fuselage structure and allow easier integration of the wing carry-through structure. However, these entry configurations tended to have very aft center-of-gravity (c.g.) locations that made entry trim and control difficult. Hence, the current SSV study is concentrating on configurations with a forward LO_2 tank as shown in Fig. 3. These configurations have a more forward intertank, payload bay, crew cabin, and associated subsystems, thereby providing a more forward entry c.g. Two separate propellant tanks were used to avoid the operational issues associated with the use of common bulkheads for reusable cryogenic propellant tanks. As shown in Fig. 3, the payload bay was located in the intertank region, internal to the fuselage, to avoid the aerodynamic complexity associated with external payload bay configurations like that of Ref. 21. The crew cabin location was selected to allow crew access to the payload bay and facilitate crew ejection from the vehicle in the event of a catastrophic failure.

Configuration Optimization

The design of entry vehicle configurations that have acceptable flying qualities throughout all of the required flight regimes is a complex and difficult multidisciplinary process. This process was facilitated in this study by the use of state-of-the-art multidisciplinary design tools and methods that were described earlier. The entry vehicle is required to land at a reasonable velocity and to be trimmable and near neutrally stable throughout the hypersonic, supersonic, and subsonic flight regimes. These conditions must be met for payload-out and payload-in entry c.g. configurations. In addition, sufficient margin must be provided, beyond that required for nominal trim, to allow for vehicle control by deflecting wing elevons and a body flap throughout a range of entry conditions.

The design method used in this study is a second-order response surface methodology described earlier. Five configuration parameters that greatly affect the entry vehicle flying qualities and vehicle weight were selected for study. As illustrated in Fig. 4, they are the fineness ratio, the nose ratio, the nose droop, the wing area, and the wing location. These parameters were varied over the ranges shown in Fig. 4. The vehicle optimization parameter selected to be minimized was the total SSV dry weight. Dry weight was selected because, for the same level of complexity and technological risk, vehicle development costs tend to vary as a function of dry weight.

Initially, the CCD methodology discussed earlier was used to statistically select which configurations must be examined to adequately characterize the parameter space. For 5 parameters, 27 configuration designs were required to provide an accurate second-order regression fit. Hence, 27 different vehicle point designs were performed using the tools described earlier. For each vehicle point design, each of the configuration variables (fineness ratio, nose ratio, etc.) was held at a value specified by the CCD methodology. A total dry weight was thus obtained for each SSV configuration. A second-order regression fit was then performed using these 27 dry weight values, and an equation was obtained that related dry weight to each of the configuration variables of interest. Unconstrained optimization of the vehicle dry weight over the desired parameter space could then be performed; however, analytical constraints on the SSV landing velocity and entry trim and stability characteristics were required.

Equations for the required constraints were also obtained through a second-order regression analysis. Initially, an optimal POST entry trajectory was run using a reference SSV to determine what angles of attack, α, and dynamic pressures, q_∞, were desirable for the entry vehicle during each flight regime. A hypersonic condition, a super-

Table 1 Reference conditions for RSM pitching moment analysis

Condition	M	α, deg	δ_{elev}, deg	δ_{bf}, deg
Subsonic	.3	12	0	0
Supersonic	2	15	0	0
Hypersonic	20	30	8	5

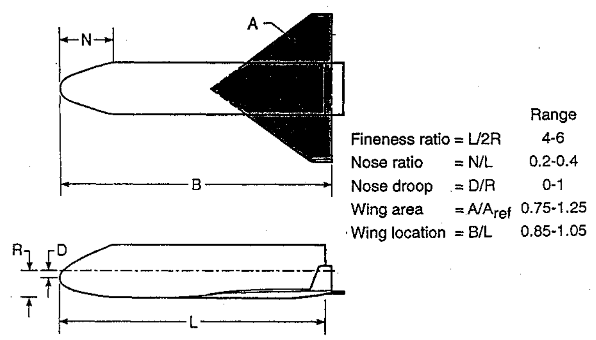

Fig. 4 Configuration parameters for RSM analysis.

Table 2 Trimmed aerodynamic flight characteristics of optimum SSV configuration

Condition	δ_{elev}, deg	δ_{bf}, deg	V_{land}, knots	L/D	$C_{m\alpha}$
Subsonic					
Payload in	−3	0	208	4.8	−0.0022
Payload out	0	0	206	4.8	−0.0008
Supersonic					
Payload in	−4	−4	—	1.8	0.0001
Payload out	1	−4	—	1.9	0.0003
Hypersonic					
Payload in	0	−4	—	1.5	−0.0019
Payload out	0	6	—	1.5	−0.0009

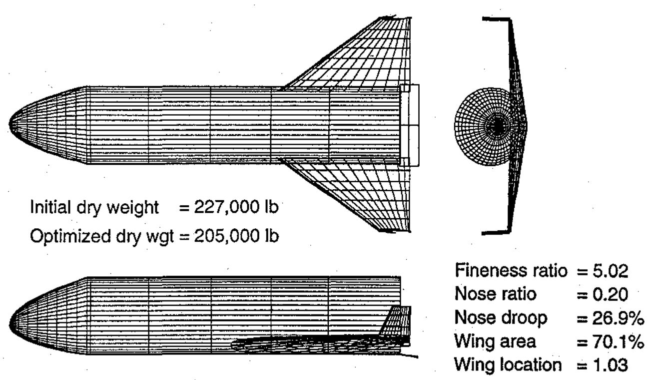

Fig. 5 Optimum configuration and parameter values.

sonic condition, and a subsonic condition were selected to characterize the entry profile. Table 1 gives the Mach number, M, α, and q_∞ for each condition. APAS was then used to calculate the pitching moment coefficient, C_m, at each of the three flight conditions using the body flap deflections, δ_{bf}, and elevon deflections, δ_{elev}, shown in Table 1. The entry c.g. used in each C_m calculation assumed the return payload was half (10,000 lb) of the design payload to provide control margin over the total payload range. A hypersonic C_m for fixed control surface deflections was thus obtained for each of the 27 configurations. A regression analysis was then performed, and a second-order equation was obtained relating hypersonic C_m to the configuration variables of interest. Similar equations were obtained for supersonic and subsonic C_m. APAS was also used to calculate the first derivative of C_m with respect to $\alpha (C_{m\alpha})$ at each flight condition to evaluate static stability. The entry c.g. used in each $C_{m\alpha}$ calculation assumed the payload bay was empty to provide the worst case (most aft c.g.) for entry stability. Using second-order regression analysis, equations relating $C_{m\alpha}$ in each flight regime to the configuration variables were obtained in a similar manner to those obtained for C_m. A second-order equation relating landing velocity, V_{land}, to the configuration variables was obtained using a similar analysis.

These equations were then used in a nonlinear optimizer to determine the minimum dry weight configuration that met the entry flight constraints. In the optimization process, the landing velocity was constrained to be less than 205 kt, and the hypersonic, supersonic, and subsonic C_m and $C_{m\alpha}$ values were constrained to be near zero. The configuration obtained from this optimization process is shown in Fig. 5. The SSV dry weight of 206,500 lb is significantly less (9%) than the 227,000-lb weight of the initial reference vehicle. The figure also indicates the optimum values for fineness ratio, nose ratio, nose droop, wing area, and wing location. A configuration point design was then performed, holding the configuration parameters at the optimum values, to verify the dry-weight prediction of the second-order model. The dry weight of the SSV point design was within 1% of the prediction of 206,500 lb. Some aerodynamic characteristics of the optimum entry configuration at trimmed conditions are given in Table 2. The vehicle is near-neutrally stable for the payload-out condition and stable for the payload-in condition during the hypersonic, supersonic, and subsonic entry flight regimes. The vehicle can be trimmed in the pitch plane for payload-in and payload-out conditions (a c.g. shift of 2.6% of total vehicle length) during the hypersonic, supersonic, and subsonic entry flight regimes without deflecting elevons or the body flap more than 6 deg. These trim characteristics provide a very large aerosurface deflection margin for control of the entry vehicle during off-nominal conditions.

Vehicle Conceptual Design

In the configuration selection process previously described, a few simplifying assumptions were made. Once an optimum SSV configuration was obtained, some configuration refinements were made. A wing-body fairing was added, the aft fuselage was faired into the body flap, and the crew cabin was integrated on top of the vehicle. In addition, the reference propulsion system was changed from an advanced staged combustion cycle engine to a more near-term Space Shuttle Main Engine (SSME) derivative. After these changes were made, a conceptual-level vehicle design was performed using the tools and methods illustrated in Fig. 1. The vehicle point design obtained is shown in Fig. 3, and a summary of the conceptual design results in various disciplines is given next.

Flight Performance

The nominal POST ascent trajectory for the AMLS single-stage vehicle is presented in Fig. 6. Lift, drag, and pitching moment coefficient data obtained from the APAS aerodynamic code were input into the POST trajectory program. POST was then used to calculate the engine gimbal angles required to trim the vehicle in the pitch plane throughout the ascent trajectory. All seven SSME-derivative engines were simultaneously gimballed for trim. As shown in the figure, gimbal angles of ±3 deg are required for nominal vehicle trim in the pitch plane. These gimbal requirements are less than those of the current Space Shuttle, and significant margin is left for vehicle control during off-nominal conditions. As shown in the figure, the initial T/W is 1.21. The vehicle reaches a maximum dynamic pressure of 600 lb/ft^2 after 70 s. The vehicle continues to accelerate until the longitudinal acceleration limit of 3 g is encountered at 170 s. The engines are throttled to maintain this limit. As the engines are throttled, selected engines are shut down until orbital insertion occurs at 360 s into a transfer orbit with a 50-n.mi. perigee and 100-n.mi. apogee.

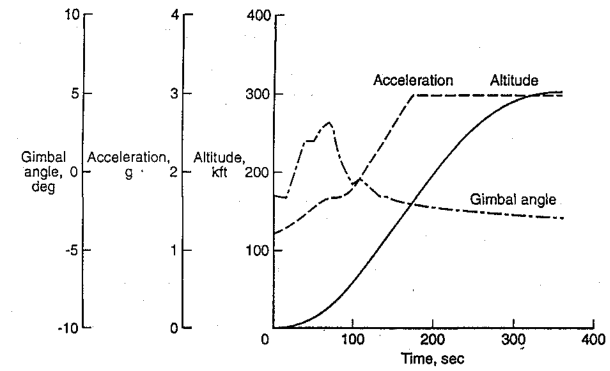

Fig. 6 AMLS SSV ascent trajectory.

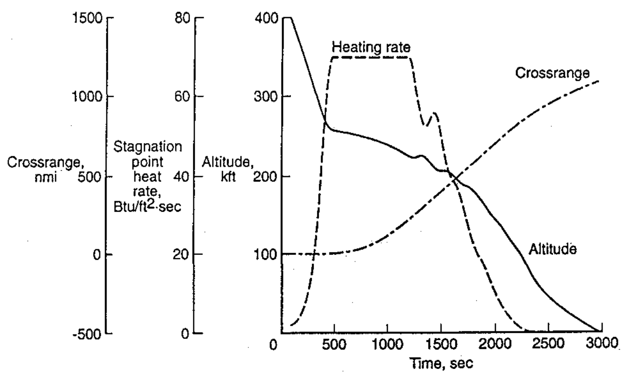

Fig. 7 AMLS SSV entry trajectory.

The nominal POST entry trajectory for the AMLS SSV is presented in Fig. 7. After performing a deorbit burn, the vehicle reaches nominal atmospheric interface (altitude = 400,000 ft) at a relative flight-path angle of −1 deg and an angle of attack of 32 deg. Throughout the majority of the entry profile, the angle of attack of the vehicle remains at 32 deg to allow hypersonic trim and maximize lift-to-drag ratio. POST was employed to minimize the maximum stagnation point heat rate during entry while still achieving sufficient cross range (a minimum of 1100 n.mi.) to allow once-around abort from a polar orbit. At an altitude of 260,000 ft, the stagnation point heat rate (based on a 1-ft reference sphere) reaches 70 Btu/ft^{2}s. The bank angle of the vehicle is then modulated between 0 and 90 deg for about 800 s to hold the heat rate at 70 Btu/ft^{2}s. This was found to be the minimum value that the maximum stagnation point heat rate could be held within and still achieve the desired cross range. When an altitude of 225,000 ft is reached, the bank angle is decreased to 12 deg, and the vehicle prepares for terminal energy management maneuvers. Using this approach, the SSV is able to achieve about 1150 n.mi. of cross range.

Materials and Structures

The major material and structural technologies assumed for the AMLS single-stage vehicle are summarized in Fig. 8. The SSV employs graphite-polyimide composite wings, intertank, nose region, fairings, and aft skirt that act as carrier panels for a durable metallic TPS on most windward and leeward surfaces and for an advanced carbon-carbon (ACC) TPS on the vehicle nose and leading edges. All aerodynamic control surfaces are of an ACC hot structure design. The integral hydrogen and oxygen tanks are constructed of aluminum-lithium (Al-Li) alloy 2095 and use external, closed-cell foam insulation. The thrust structure also utilizes Al-Li 2095. All fuselage and cryogenic tank structures utilize internal ring frames and stiffeners. Although a detailed structural analysis of the AMLS SSV was not performed, the vehicle structural weights were obtained from a finite element analysis of a similar two-stage vehicle described in Ref. 22. This two-stage vehicle was similar in configuration, used the same material technologies and structural concepts, and experienced similar loads during launch, ascent, entry, and landing.

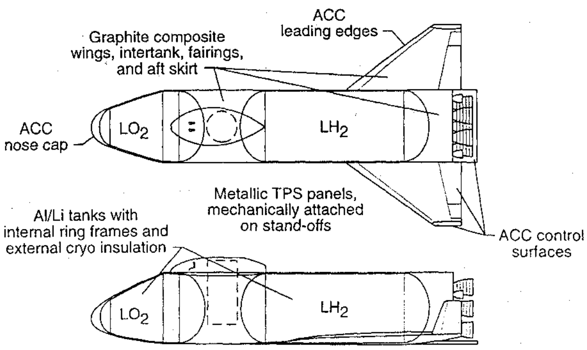

Fig. 8 AMLS SSV materials.

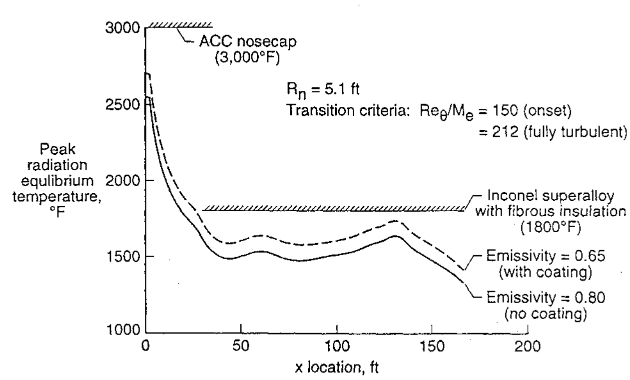

Fig. 9 SSV entry windward centerline peak heating distribution.

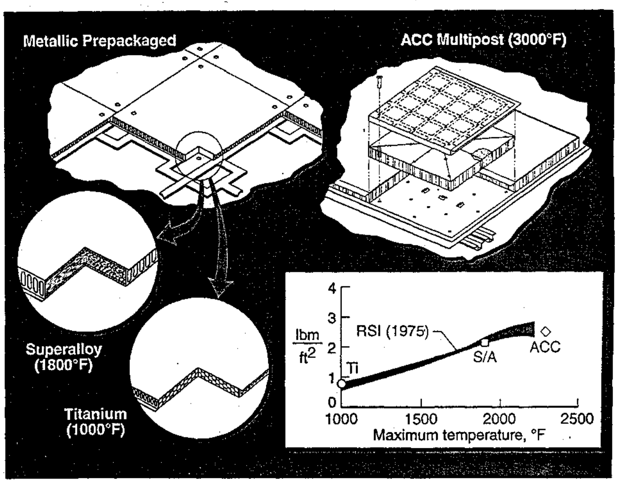

Fig. 10 Durable TPS concepts.

Aeroheating

Using the entry profile described earlier, the Miniver program was used to perform a windward centerline heating analysis of the single-stage vehicle. Some of the results of this analysis are presented in Fig. 9. The maximum value of the radiation equilibrium temperature along the windward centerline throughout entry is plotted. For an emissivity of 0.8, the resulting temperatures require the use of an ACC hot structure or multipost panel from the nose tip to 17 ft (10% of vehicle length) aft along the centerline. From that point to the rear of the vehicle, Inconel superalloy (S/A) TPS panels with fibrous insulation are used. These panels have been tested to 2000°F and are used on portions of the AMLS SSV not exceeding 1800°F. The uncoated Inconel panels have an emissivity of 0.65, whereas coated panels have an emissivity of 0.8. The baseline SSV uses a coating described in Ref. 23. For windward and some leeward regions with temperatures less than 1000°F, titanium multiwall TPS panels are employed. Figure 10 shows the three durable TPS concepts used on the AMLS vehicle. As shown in the figure, all concepts are similar in weight to the current Shuttle reusable surface insulation (RSI), which is less durable and more difficult to service. Further details on the construction and testing of each of these TPS concepts are contained in Ref. 23.

Aerodynamics

The APAS aerodynamics program was used to calculate lift, drag, and pitching moment coefficients for the AMLS SSV. The aerodynamic coefficients used in the SSV ascent trajectory do not include base drag effects because the main engines are burning until orbital insertion, whereas the aerodynamic data for the entry trajectory include base drag. The reference entry configuration was demonstrated to be trimmable in the pitch plane at payload-in and payload-out c.g. conditions at subsonic, supersonic, and hypersonic flight conditions. The pitching moment coefficient data at each of these conditions are shown in Figs. 11–13. The elevon and body flap deflections required to trim the vehicle are relatively small, and significant control surface margin is available for control during off-nominal conditions. The tip fins on the reference SSV are not designed to provide static lateral stability but to provide an active yaw control surface throughout the entry flight regime. The tip fin control surfaces are sized to counteract the yawing moment produced by 2 deg of sideslip angle at a hypersonic entry condition.

Propulsion

The reference AMLS SSV uses seven SSME-derivative engines that are gimballed for vehicle control during ascent and abort. The performance characteristics of one of these engines are summarized in Table 3. The SSV engines are nominally used at a power level of 100% rather than the maximum power level of 109%. Derating the engine thrust in this manner provides significant thrust margin and greatly increases the reliability of the engine. The use of seven engines allows a safe abort, with intact vehicle recovery, in the

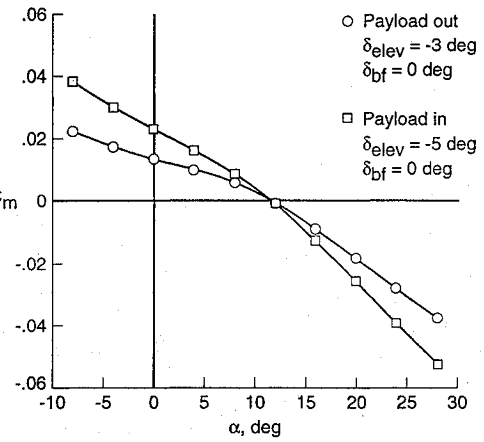

Fig. 11 SSV subsonic pitching moment characteristics ($M = 0.3$).

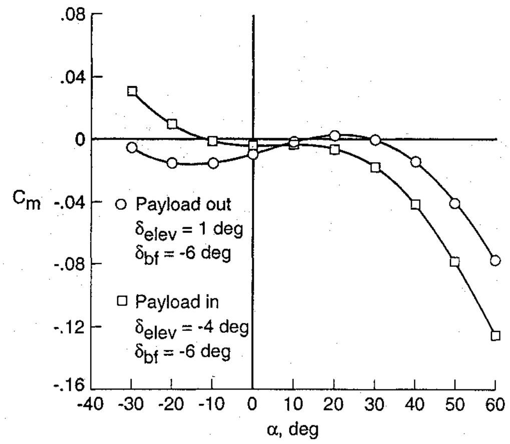

Fig. 12 SSV supersonic pitching moment characteristics ($M = 2.0$).

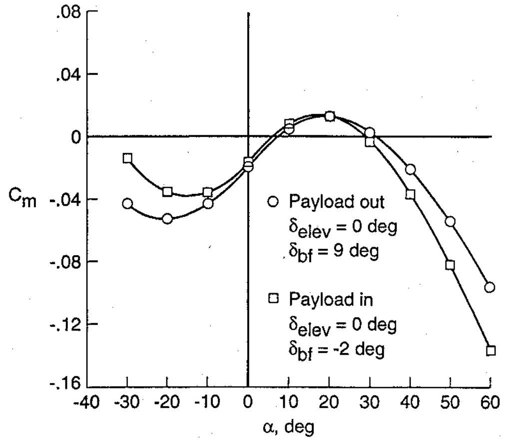

Fig. 13 SSV hypersonic pitching moment characteristics ($M = 20$).

event of a forced engine shutdown at any time during the ascent trajectory.[24]

The SSME-derivative engine used in this study differs from the current SSME in a number of ways. Extended-life, high-pressure turbopumps are used with hydrostatic bearings. Electromechanical actuators are used for gimbals and valves. Other improvements include integrated health monitoring, a Block II controller, and a two-duct hot gas manifold.[25] A number of baffles and acoustic cavities would also be removed to improve the combustion zone efficiency. No advanced materials or altitude-compensating nozzles are assumed. Each engine employs a nozzle with an area ratio of 50. This area ratio was chosen to minimize total SSV dry weight.

Table 3 SSME-derivative engine performance characteristics

Vacuum thrust, lb	463,900
Sea-level thrust, lb	402,600
Chamber pressure, psia	3,000
Area ratio	50
Vacuum specific impulse, sec	447.3
Sea-level specific impulse, sec	387.9
Oxidizer/fuel	6.0
Weight, lb	6,780

Operations

Consideration was given to ground and flight operations from the outset of the AMLS single-stage vehicle design. Many of the evolutionary technology advances employed on the SSV contribute to significant weight reductions and performance benefits over the current Space Shuttle; however, a large portion of this weight savings has been applied to aspects of vehicle design that enhance the operability, reliability, and safety of the system. Hydraulic systems are replaced with all-electric systems employing electromechanical actuators for engine gimbals and valves, aerodynamic surface controls, and landing gear. Toxic hypergolic propellants in orbital maneuvering and reaction control systems are replaced by cryogenic hydrogen and oxygen, providing commonality of propellant type with the main propulsion system. The SSME-derivative main engines would use integrated health monitoring, controller advancements, built-in test equipment, and single-cast construction to reduce welds wherever possible. The advanced avionics employed are lighter and more powerful and can help decouple the vehicle from a majority of ground-based mission control functions, thus introducing a significantly higher level of autonomy. Subsystems that are fault tolerant and possess built-in test equipment to monitor system conditions are essential for streamlined operations, especially in the propulsion system. Subsystem units, where feasible, are of a modular design for easy removal and replacement. A durable metallic TPS is employed that is easy to remove and replace. Allowing for single engine fail-safe capability during the SSV ascent trajectory enhances crew and vehicle safety. The use of standardized payload canisters with common vehicle interfaces allows off-line processing of payloads, thereby greatly streamlining operational procedures. The use of a single stage eliminates stage-integration manpower and facility requirements and risk associated with stage availability. The use of a single-stage rather than a two-stage system also eliminates the need to develop, manufacture, and service two dissimilar vehicles.

Summary

A rocket-powered, single-stage launch vehicle has been designed as a part of the AMLS study to examine options for anext-generation manned space transportation system. In the design of the AMLS SSV, a number of configuration trade studies were performed in an attempt to optimize the reference vehicle with respect to important vehicle parameters like dry weight and operational complexity. This configuration design process used a RSM for multidisciplinary optimization of the SSV entry configuration. The RSM was used to determine the minimum dry weight entry vehicle to meet constraints on landing velocity and on subsonic, supersonic, and hypersonic trim and stability. The optimum configuration obtained from the RSM analysis is 9% less in total dry weight than the initial reference configuration. The vehicle is near-neutrally stable for the payload-out condition and stable for the payload-in condition during the nominal hypersonic, supersonic, and subsonic entry flight regimes. The vehicle can be trimmed in the pitch plane for payload-in and payload-out conditions (a c.g. shift of 2.6% of total vehicle length) during the nominal hypersonic, supersonic, and subsonic entry flight regimes without deflecting elevons or the body flap more than 6 deg in either direction. These trim characteristics provide a very large aerosurface deflection margin for control of the entry vehicle during off-nominal conditions.

Once a reference configuration was selected, a multidisciplinary conceptual design was performed. The vehicle aerodynamics were evaluated, a propulsion system was selected, ascent and entry trajectories were analyzed, a centerline heating analysis was performed, baseline structural concepts and thermal protection system materials were selected, and a weights and sizing analysis was performed. In the selection of vehicle subsystems, special attention was given to reducing ground and flight operations support requirements. Exploitation of a number of new technologies results in significant weight savings that can be returned to the vehicle in the form of robust subsystems, increased reliability, and assured mission success. Technology developments in the areas of reusable cryogenic tankage, low-cost main propulsion with integrated health monitoring, low-maintenance thermal protection systems, electromechanical actuators, and self-monitoring fault-tolerant systems will be instrumental in assuring the readiness of low-cost, next-generation space transportation systems.

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