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Evaluation of the National Launch System as a Booster for the HL-20

James B. Duffy*
Rockwell International, Huntsville, Alabama 35806
and
Jack W. Lehner† and Bill Pannell‡
NASA Marshall Space Flight Center, Alabama 35812

The capability of a proposed national launch system (NLS) to boost the personnel launch system (PLS) manned vehicle has been examined. A reference NLS configuration, the NLS-2 1.5 stage vehicle, and a reference HL-20 PLS configuration were used for the study. Performance has been analyzed for several PLS insertion orbits to support the Space Station Freedom resupply mission. The reliability of the NLS launch vehicle and its contribution to crew safety requirements have been determined. The launch-processing and launch facility requirements of these combined systems were also analyzed. Previous studies of these two systems have focused on either the PLS manned element or NLS launch vehicle. This paper combines the results of prior studies in an analysis of the integrated NLS/PLS configuration. This analysis has found the proposed NLS 1.5 stage launch vehicle to be an excellent booster for the PLS. Predicted performance margins for this launch-vehicle configuration are more than adequate, and acceptable reliability and safety levels are anticipated. Integration of this NLS/PLS configuration into NASA mixed-fleet launch architectures is feasible.

Introduction

STUDIES of next-generation manned launch systems that augment or even replace the NASA Space Shuttle have identified several promising options. Among the candidate launch systems are the NASA personnel launch system (PLS) and NASA/USAF national launch system (NLS). Both of these systems have been studied in some detail by government and industry teams. The focus of these studies, however, has been on one system or the other and not on an integrated PLS/NLS system.

The NLS family of launch vehicles is a joint NASA-USAF program that has evolved from the ALS launch vehicle family and a cargo-only version of the Space Shuttle system known as the Shuttle-C. To date, the NLS program has focused on launch vehicle development to perform a range of cargo delivery missions with the objective of being a man-rated booster in the future. The NLS program has identified some of the design constraints and system requirements that will be required to carry manned payloads. The initial flight configurations of NLS vehicles may or may not contain the necessary systems for launching payloads such as PLS. The required systems could be added later as vehicle modifications. Since most of the proposed NLS missions will be cargo-related, the vehicle development efforts must first achieve efficient designs for these missions. As is the case for the current PLS studies, this is a sufficiently challenging task to focus the NLS study efforts.

A more recent study effort initiated by the Marshall Space Flight Center (MSFC) is the advanced transportation systems studies (ATSS). This study consists of four parts and is based on the study of manned transportation systems to space. Within this study effort, the role of the NLS launch vehicle as a booster for the PLS manned system has been examined. Although other manned launch vehicle boosters are also being examined, a key objective is to understand the capabilities of NLS in this mission and identify any manned booster issues or constraints that should be addressed by the NLS program.

This paper documents some of the work that is applicable to the question of NLS as a manned launch vehicle booster. The work represents analyses based on the published results of both the PLS and NLS studies. Since both the PLS and NLS are on-going studies, the reference systems' configurations may not reflect current designs, but attempts were made to accurately reflect the most recent designs and program definitions.

Launch Vehicle Configurations

The NLS family of launch vehicles consists of three classes of payload delivery capability to LEO: 10,000- to 20,000-lb class (NLS-3), 50,000-lb class (NLS-2), and 150,000-lb class (NLS-1). A representative vehicle configuration for each of these families is shown in Fig. 1. The NLS-3 is intended to be a versatile launcher for a variety of small, unmanned payloads. This payload capability is too small for the NLS-3 to be considered a booster for the envisioned PLS concepts. The NLS-2 is the most appropriate of the NLS family of vehicles for launching the PLS concepts. Although the design studies for this vehicle are driven by unmanned payload delivery requirements, the resultant configurations remain quite sufficient for the PLS mission. The NLS-1 is a heavy-lift version of NLS and is designed to deliver upwards of 150,000 lb of payload to low Earth orbit. This payload capability is much greater than necessary to launch the PLS and makes this NLS family member unsuited for the PLS mission. Future missions that would

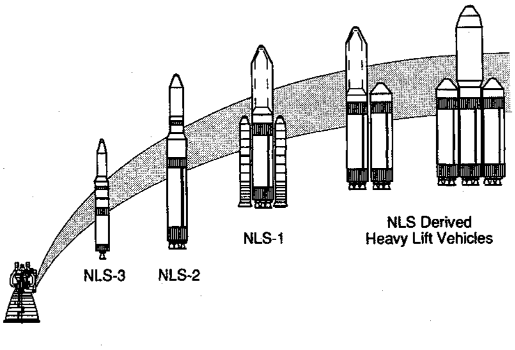

Fig. 1 NLS family of launch vehicles.

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*Program Manager, Space Systems Division.

†Contract Technical Representative, Program Development.

‡Systems Engineer, Program Development.

Table 1 NLS 1.5 stage launch-vehicle weights summary with PLS payload

Element	Weight, lb
Core stage with 2 STMEs	127,550
Booster module with 4 STMEs	70,700
MPS propellant at liftoff	1,757,703
Total PLS launch weight	33,800
Gross liftoff weight	1,989,753
Boost-module staging weight	78,312
Core-module staging weight	145,882
Total usable propellant	1,731,759
Flight-performance reserves	5,571

Table 2 PLS (HL-20) weights summary for NLS-2 booster

Element	Weight, lb
PLS inert weight	19,170
Personnel and provisions	1,953
Fluids and residuals	318
Propellants and consumables	4,045
Adapter and launch escape system	8,314
Total launch weight	33,800

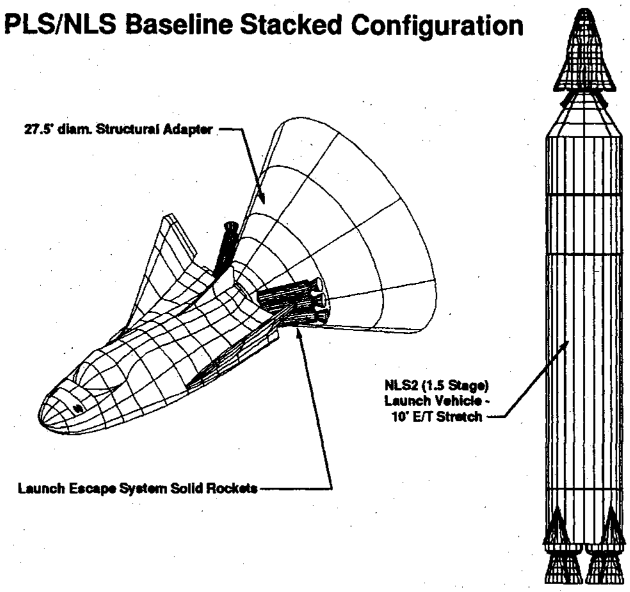

Fig. 2 PLS (HL-20) and NLS-2 reference configuration.

require concurrent delivery of large payloads with manned payloads such as PLS may find this launch vehicle appropriate.

The work presented in this paper was based on the NLS-2 launch vehicle. The design configuration for this vehicle has varied over the course of the NLS study. The propellant tanks, though based on the external tank (ET) of the Space Shuttle, have varied from the standard (Shuttle-sized) ET to those with either a 5- or 10-ft stretch. The space transportation main engine (STME) configurations used for this launch vehicle have also changed, from 580,000- to 650,000-lb thrust (vac) designs. Weight estimates, propellant loads, subsystem definitions, and trajectory parameters continue to change as the concept design matures. The concept has remained, however, to be an expendable 1.5 stage vehicle with all-liquid propulsion, STME engines, and ET-based propellant tanks. The 1.5 stage designation refers to the concept of dropping (staging) some of the engines used in the initial flight stages, but not a complete propulsion stage [engine(s) and propellant tank]. The Atlas launch vehicle, which dropped two of the three engines used in first-stage flight, is an example of this type of booster. The NLS-2 design is based on dropping four of the six STMEs used in its first-stage flight. The engines may be staged as individual engines or a cluster of engines within a propulsion module structure.

The reference configuration of the NLS-2 launch vehicle used for this paper is derived from the NLS reference design as baselined in May 1992. This proposed configuration includes a 10-ft stretch of the external tank, six STMEs (650,000-lb thrust each), and the staging of four STMEs in a propulsion module. Performance analyses of this configuration are based on design ground rules utilized by the NLS program, including an engine-out capability, weight estimate margins, and propellant margins. The engine-out capability requires the vehicle to complete the mission with any one engine out. The worst case is one of the two sustainer engines failed at liftoff from the launch pad. The deletion of a payload shroud normally included in the vehicle design and charged as vehicle weight is unique to the NLS-2 configuration for the PLS mission. This shroud is not required for the PLS payload as the PLS is designed for aerodynamic flight, and the weight of this payload shroud (approximately 12,000 lb) is convertible to payload capability for the PLS mission. A weight summary of this NLS reference configuration is provided in Table 1.

The PLS configuration is the HL-20 design that was further developed by Rockwell International and Lockheed for the LaRC studies. The configuration details were documented in the study final report (Ref. 1). The only changes necessary were in the PLS-launch vehicle adapter configuration. In the PLS study, this adapter was sized for the ALS launch vehicle which had a larger diameter than the NLS. A proposed NLS payload adapter was used in this paper that would interface with the PLS adapter/launch-escape system (LES). The weight estimates for the PLS and its adapter are provided in Table 2. These weights are all considered payload-chargeable for the NLS booster. The PLS and NLS-2 configurations are shown together in Fig. 2 (not to scale). These configurations were used for the analyses contained within this paper. This combination represents a unique configuration that has not previously been analyzed as an integrated system by either the NLS or PLS studies.

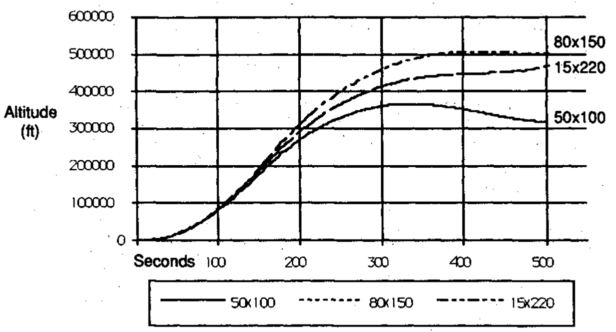

Fig. 3 NLS trajectory profile summary: acceleration.

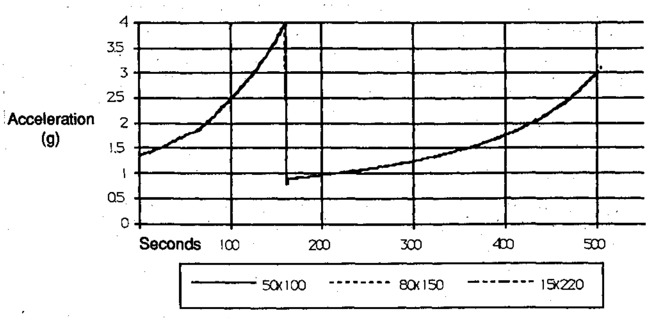

Fig. 4 NLS trajectory profile summary: acceleration.

Launch Vehicle Performance

The payload lift capability of the NLS-2 launch vehicle was evaluated in the PLS mission configuration, as described in the previous section. The performance of the NLS launch vehicle varies with the specification of different insertion orbits. The PLS study used an insertion orbit of 50×100 n.mi. for its performance analyses. The NLS study uses an insertion orbit of 80×150 n.mi. as the standard insertion orbit for NLS performance analyses, but has more recently evaluated a 15×220 n.mi. insertion orbit. Performance of the NLS-2 launch vehicle to each of these insertion orbits was calculated using a POST3D trajectory simulation tool. The trajectories analyzed were based on 3-degree-of-freedom simulations with design wind conditions and propellant reserves as currently specified for the NLS program studies. All trajectories assumed a NASA Kennedy Space Center (KSC) launch site, a 28.5-deg inclination, and that one of the STME sustainer engines failed from liftoff. Under this engine-out scenario, all remaining engines (5) are operated at 100% rated power level. A maximum acceleration level of 4 g was imposed on all trajectory simulations, but the maximum aerodynamic pressure (maximum q) was unconstrained.

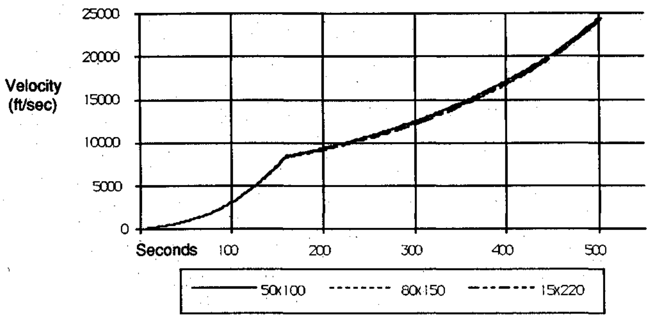

Fig. 5 NLS trajectory profile summary: velocity.

Table 3 NLS performance summary to PLS insertion orbit

Key trajectory parameters	50 ×100[a]	80 × 150[b]	15 × 220[b]
Maximum Q, psf at s	755 at 73.5	731 at 72.0	745 at 72.5
Maximum acceleration, g at s	4.0 at 159.93	4.0 at 159.20	4.0 at 159.13
Staging conditions			
Time, s	161.13	160.40	160.33
Altitude, ft	200,146	219,581	209,635
MECO conditions			
Time, s	500.81	503.73	504.00
Altitude, ft	318,399	500,661	470,612
Weight, lb	214,795	209,587	208,966
Additional payload, lb	35,113	29,905	29,284

[a] PLS reference trajectory = 50×100.
[b] NLS reference trajectory = 80×150 and 15×220.

Table 4 Orbit transfer requirements from PLS insertion to Space Station Freedom orbit

NLS performance to transfer orbit			
Destination orbit	Transfer orbit		Payload to transfer orbit
220 circular at 28.5	50×100		68,913
220 circular at 28.5	80×150		63,705
220 circular at 28.5	15×220		63,084
Upper-stage performance to reach destination orbit			
ΔV, ft/s	Isp, 1/s	Propellant burned, lb	Weight in final orbit[a]
513.1	303.0	3,533	65,380
368.8	303.0	2,364	61,341
364.5	303.0	2,315	60,769

[a] Weight in final orbit = payload weight + kick stage (TBD).

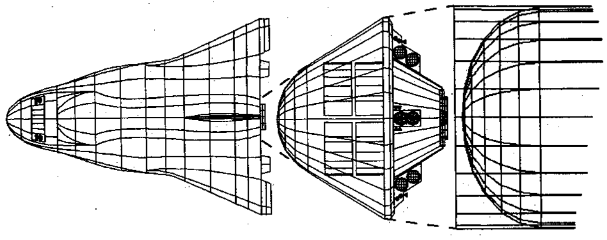

Fig. 6 PLS with caboose concept on NLS 1.5 stage booster.

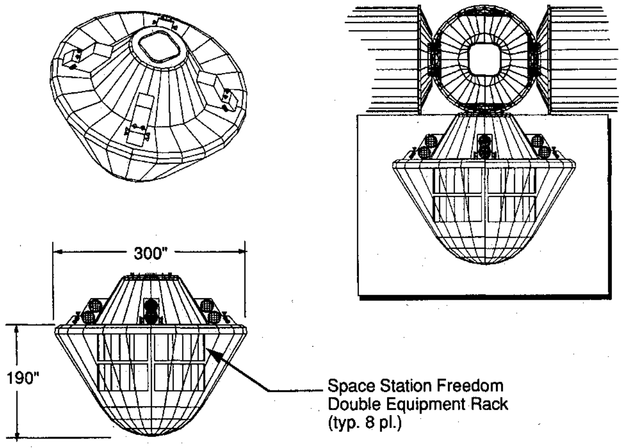

Fig. 7 PLS caboose concept at Space Station Freedom.

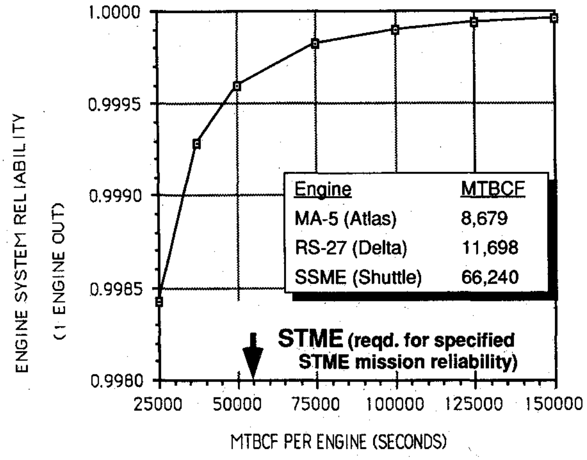

Fig. 8 NLS propulsion reliability based on STME.

The NLS/PLS configuration performance to the PLS reference insertion orbit was determined to have considerable margin, even under the engine-out scenario. At the main engine cutoff target, the NLS propellant tank had 32,200 lb of usable propellant remaining. This excess propellant can be translated into additional payload capability. The performance analysis was rerun to maximize the delivered payload for the same propellant load. The resultant payload deliverable to this insertion orbit was 68,900 lb, which includes the PLS (33,800 lb) plus an additional 35,100 lb of excess payload capability. The trajectory profile is plotted in Figs. 3–5 for several of the performance parameters. Similar trajectory simulations under the same conditions (engine out, winds, propellant reserves, etc.) to two NLS reference insertion orbits (80×150 n.mi. and 15×220 n.mi.) were also performed. Both of these simulations produced similar results as the PLS reference insertion orbit. Specifically,

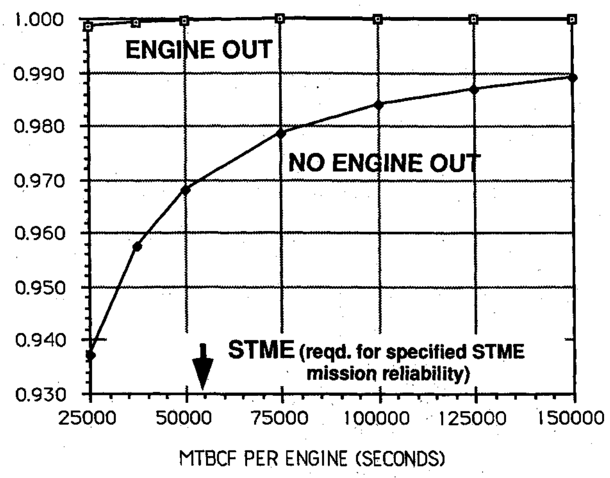

Fig. 9 NLS reliability due to engine-out capability.

Table 5 Demonstrated success of previous manned launch systems

Manned launch system	Mission success rate		Probability of safe return[a]
	Unmanned	Manned flights	
PLS/NLS-2	N/A	0.984 (est.)	0.9997
Space Shuttle	N/A	0.979	0.9830
Apollo/Saturn V	1.00	1.00	0.9996
Gemini/Titan II	0.53	1.00	0.9990
Mercury/Atlas	0.61	1.00	0.9978
Mercury/Redstone	0.85	1.00	0.9981

[a]Boost phase only.

the NLS-2 booster had considerable performance margin for the PLS mission for both trajectories. The 80×150 n.mi. orbit resulted in somewhat less additional payload (29,900 lb), and the 15×220 n.mi. orbit produced the least additional payload (29,300 lb). The trajectory profiles for each of the insertion orbit trajectories are compared in Figs. 3–5. A direct comparison of the key parameters from each trajectory is provided in Table 3. The maximum dynamic pressure for all of the analyzed trajectories is less than 800 psf. Also, note that the maximum acceleration (4 *g*) was reached just prior to staging of the four booster engines. Acceleration at orbit insertion was just over 3 *g* for all of the trajectories analyzed. Obviously, the NLS-2 launch vehicle has sufficient performance for launching the PLS to most any insertion orbit desired. The orbit of most interest for the PLS mission, however, is the Space Station Freedom (SSF) orbit. Because the PLS/NLS configuration has excess payload capacity to the SSF insertion orbit, it is feasible to utilize this excess capacity to deliver some additional cargo to SSF along with the PLS. The marginal cost of launching additional cargo payloads with the PLS would make such a concept very cost-effective. Additional propulsive maneuvers beyond NLS insertion orbit conditions are required to rendezvous the PLS (and additional cargo) with the SSF. The delta-V requirement from each of the reference insertion orbits to SSF is shown in Table 4. By assuming a nominal upper-stage engine-specific impulse (Isp), the propellant required to deliver the final payload to SSF can be determined. This final payload would consist of the PLS itself and any additional cargo, plus the dry weight of a propulsive unit (kick stage) needed to perform the maneuver. The data in Table 4 show that the NLS with any moderate kick stage can deliver the PLS and up to 31,580-lb additional mass to the SSF orbit.

A PLS caboose is being evaluated to utilize this excess launch capacity of the NLS/PLS configuration. The caboose would be similar to the resource module that attaches to the aft end of the Hermes spaceplane concept, but could provide a cargo return capability as well. Based on the results presented in Table 4, this PLS caboose concept might permit an additional 12,000 lb of cargo to be delivered to SSF on each PLS mission. The Space Shuttle utilizes a mini-pressurized logistics module to deliver eight international standard payload racks on a Space Station logistics mission. The current design of this module identifies a gross weight of 20,000 lb for the eight-rack payload, each rack constituting an average of 1000-lb payload weight. This translates to a payload fraction of 40% for the logistics module. For an equivalent payload fraction, a PLS caboose concept could yield a net additional payload of 12,000 lb delivered to SSF with each PLS mission. If an equal payload mass was to also be returned to Earth by this caboose concept, the dry weight would necessarily have to increase for thermal protection systems. The decreased net payload fraction for a two-way (deliver and return) cargo transport would reduce the available cargo capacity of this concept. A typical payload fraction of 60% has been shown[2] for similar concepts in recent studies by MSFC and General Dynamics. The current PLS caboose study approach is to size the vehicle to carry eight SSF racks (8000 lb) and strive for a payload fraction of greater than 40%. The payload fraction of the PLS caboose concept can be improved over traditional cargo return vehicles by utilizing system functions already provided by the PLS. Integration of common systems and structures is also possible with this approach and would result in even higher payload fractions for the caboose. The current study configuration of the PLS caboose is shown in Fig. 6. The caboose utilizes the volume created by the transition region from the PLS adapter to the forward skirt at the top of the NLS oxygen tank. The NLS payload adapter is utilized as a structural element of the caboose and converts what would have been an expendable shroud into useful payload. The PLS caboose configuration is a preliminary design that is used for payload integration layouts, subsystems sizing, and aerodynamic analyses. Additional configurations are also being examined. The docked configuration of this concept at the Space Station is shown in Fig. 7, and clearance issues with the SSF modules are seen as a primary concern for such cargo vehicles.

The continued evaluation of cargo-carrying systems to be flown with the PLS is seen as an appropriate study effort in order to utilize the NLS launch vehicle to its maximum potential in the PLS mission. The excess payload capacity of the NLS makes an ideal situation for the cost-effective delivery and return of both man and cargo payloads to SSF.

Reliability and Safety

The proposed NLS launch vehicle provides no escape systems for the PLS. In the event of a mission abort, the PLS is entirely responsible for the crew escape and recovery functions. The PLS escape systems, which include the PLS adapter and several solid-rocket escape motors, are charged as payload weight for the NLS launch vehicle. The NLS will, however, have an emergency detection system that will notify the PLS crew of any critical NLS system malfunction. The mission abort decision will be made by the PLS, which then issues the abort/escape commands. For those failures that do not allow sufficient crew response times to activate abort/escape systems, the emergency system will provide an automatic abort command to the PLS. This approach is very similar to that employed on the Mercury and Gemini programs, which also used manned spacecraft (capsules) on expendable launch-vehicle configurations.

Table 6 NLS/PLS launch-processing facility requirements

Facility	Function	Status
HPF	PLS inspection, maintenance, and servicing	New
DSF	PLS safing and hazardous fluid deservicing	New
APF	Adapter assembly and processing	New
CA/PF	NLS booster assembly and processing	New
VAB	NLS/PLS mating	Modified[a]
MLT	NLS/PLS transport to pad and launch fixture	New
LC39	NLS/PLS fueling, checkout, and launch	Modified[a]
SLF	PLS landing facility	Existing[a]

[a]Shared facility with Space Shuttle system.

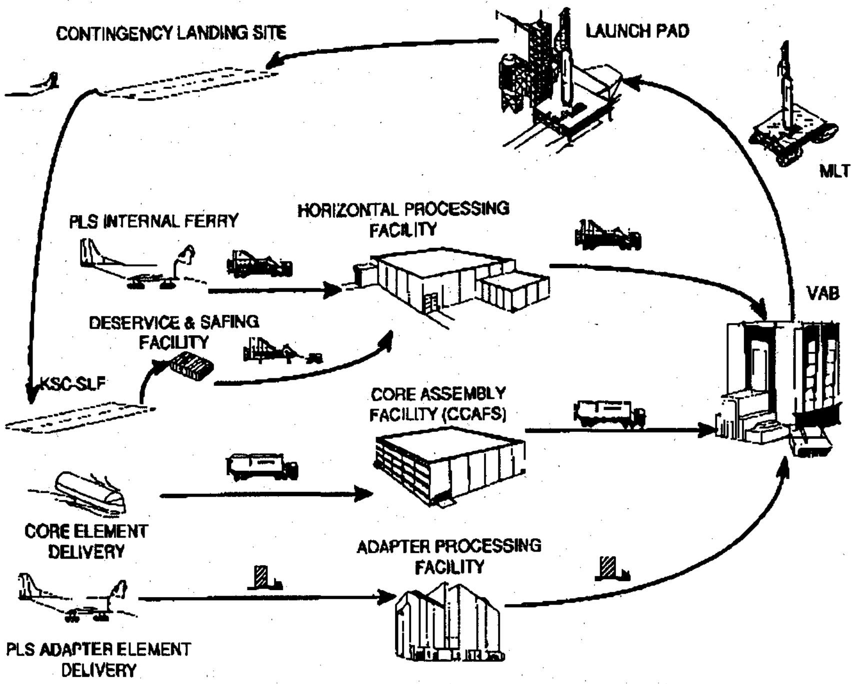

Fig. 10 PLS/NLS launch-processing flow diagram.

Table 7 NLS/PLS launch processing facility utilization

Facility/resource capability					
Name	HPF	VAB-4	CA/PF	MLT	Pad
Location	KSC	KSC	CCAFS	KSC	KSC
Status	New	Modified	New	New	Modified
Design maximum utilization	23%	37%	22%	100%	31%
Throughput capacity					
Planning at 80% (flows/yr)	46.8	28.6	48.4	10.7	34.3
Maximum at 100% (flows/yr)	58.5	35.8	60.6	13.4	42.8

During a mission abort, the NLS will likely have to perform certain functions to enhance the crew-escape function. It is anticipated that engine shutdown and STME thrust-vector-control-lock (or null) commands will be issued to the NLS systems during an abort. A delay or hold on range safety destruct systems until crew escape is completed is also expected. Identification of the required NLS abort functions has not been attempted yet, but will be examined in future activities under the ATSS study. Although the NLS contributes only minimally to the PLS escape function, the NLS does provide a highly reliable launch system for the PLS that will minimize the need to exercise the abort systems. Current NLS configurations will provide the payload with an engine-out capability that greatly improves the probability of mission success. The STMEs that power the NLS are also expected to have extremely high reliability. Based on the data shown in Fig. 8, the STME should have a reliability significantly better than current expendable launch-vehicle engines and most likely will reach the reliability levels of the Space Shuttle's SSMEs. This combination of extremely reliable engines and an engine-out capability results in a highly reliable NLS launch vehicle, as illustrated in Fig. 9. This level of launch-vehicle reliability is significantly better than that of any previous manned launch system. The Mercury and Gemini manned systems were launched by relatively unreliable rockets that had been converted to the manned mission role. Table 5 illustrates the reliability that these early manned boosters had demonstrated prior to their manned missions. Although the demonstrated reliability of these rockets for the manned missions was high (no in-flight aborts were ever executed for any U.S. manned launch), the basic vehicle reliability was quite low.[3] Clearly, the man-rating activities of the time yielded exceptional results with these vehicles. The Space Shuttle is also an extremely reliable launch system, but suffers from limited escape systems. This condition places especially high demands on the system reliability to achieve satisfactory crew safety levels.

The NLS/PLS configuration will combine the NLS's high-reliability engines and engine-out propulsion system capability with the escape systems of PLS. This combination of reliability and safety should result in very high mission success rates and an excellent probability of safe crew return. Comparison of the NLS/PLS configuration with previous manned launch systems in Table 5 illustrates how effective this combination is.

Launch-Vehicle Processing

An analysis was performed of the launch-processing facilities' requirements for the combined NLS/PLS system. The facility requirements for the NLS were obtained from studies[4] performed for the NLS program. This report identified the facility requirements and projected launch-processing times in these facilities for each of the NLS launch vehicle elements. The launch-processing facility requirements and processing times for the PLS were obtained from the PLS final report.[1] The key facilities for the combined NLS/PLS system are listed in Table 6. Note that both of these systems plan on utilizing portions of the existing Space Shuttle launch facilities at KSC. The analysis of the integrated NLS/PLS systems facilities was performed using the launch-processing simulator program STARSIM.[5] This simulator was developed for analysis of the Space Shuttle and successfully verified using actual Shuttle launch-processing history. The STARSIM model has been modified to analyze other launch vehicles and facilities. The key facilities and their launch-processing timelines for each of the system's elements were required to analyze the NLS/PLS system. The simulation flow diagram and system elements are shown in Fig. 10. A PLS fleet size of four was assumed for this analysis. Although the planned number of PLS vehicles is greater than this in the PLS final report, the four-fleet size was chosen to permit a direct comparison with the existing Space Shuttle fleet. The STARSIM analysis found that the NLS/PLS system could be launched at a rate of 13 flights per year. The limiting factor was the mobile launch tower that transports the integrated NLS/PLS configuration to the launch pad. All other facilities used in the simulation were utilized at much lower rates, as shown in Table 7. If higher than 13 flights per year are required for the PLS, the addition of a similar launch tower would permit flight rates of 20 or more per year. The NLS/PLS flight-rate analysis was based on exclusive facility utilization, as if the NLS/PLS was the only system requiring the listed facilities. This is likely an unrealistic situation as the Space Shuttle will continue to utilize some of these facilities at varying rates for years to come. The NLS will utilize many of these same facilities for its unmanned missions as well. The introduction of even more launch vehicles into the NASA launch infrastructure for proposed Lunar and/or Mars exploration programs will also place further demands on some of the KSC launch facilities. The actual launch rates achievable by the NLS/PLS system will require a mixed-fleet analysis of the several launch systems. The flight-rate projections of each launch vehicle will determine the true answer for the NLS/PLS configuration. The analysis performed to date, however, indicates that the NLS/PLS configuration can readily adapt to a mixed-fleet operation at KSC because of its low utilization rate of the key KSC facilities.

Conclusions

The NLS 1.5 stage launch vehicle has been found to be an excellent booster for the PLS HL-20 manned vehicle. The NLS provides sufficient payload lift capability with significant performance margin. Even under the engine-out scenario, the NLS excess payload capability allows the potential of carrying additional cargo payload on each PLS mission. This capability may even allow for the two-way transportation of cargo payload with PLS, both to the Space Station Freedom and return to Earth. The NLS will provide the PLS with an exceptional high-reliability booster. The reliability of the new STME engines that are coupled with an engine-out propulsion system design will ensure high mission success rates for the PLS mission. This high reliability complements the PLS escape-system functions to provide a safe launch system for manned space flight. The NLS and PLS systems should be able to attain flight rates greater than those of the current Space Shuttle system. Low facility utilization rates at the KSC launch site will allow mixed-fleet operations with other NASA launch vehicle systems.

Acknowledgments

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