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Shuttle-C: A Shuttle Derived Launch Vehicle

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The Shuttle-C will usher in a new era of transportation capability for the United States. It will provide a nearterm, unmanned heavy lift launch capability based upon existing, in-place technology. Shuttle-C (for cargo) uses the main engines, solid rocket boosters, external tanks, and launch facilities of the present space shuttle. The shuttle orbiter is replaced by an unmanned cargo carrier. Shuttle-C is designed to place payloads weighing 100,000 to 150,000 pounds into low earth orbit, compared to the space shuttle's design capacity of 65,000 pounds. It is intended for launch and assembly of large space structures such as the Space Station, and for launching large planetary payloads requiring heavy upper stages, as well as a test bed for advanced technology developments.

Shuttle-C is a candidate new initiative for NASA's FY 1989 budget. The proposed vehicle would be developed under the leadership of the Marshall Space Flight Center. This paper will describe the design and development effort underway, and provide the status of the Definition Study Contracts awarded in late 1987.
The chief purpose of the study is to determine whether the vehicle - known as the Shuttle-C (for cargo) - would be cost effective in assembling and operating the Space Station.

The results of the study will be considered part of the studies already underway of a heavy lift launch vehicle. This vehicle, known as the Advanced Launch System (ALS), is being jointly studied by the Air Force and NASA. Elements of the modular ALS will also be considered as alternatives for aiding Space Station assembly and/or operations. A joint DOD/NASA steering group will monitor the progress of the studies.

The NASA-led Shuttle-C study, includes Air Force participation and concentrates on modification of existing systems and facilities. The Air Force-led ALS study concentrates on systems incorporating advanced technologies. The results of the Shuttle-C efforts will be integrated with the other ALS studies and enable the steering group to formulate national heavy lift vehicle strategy that may best accommodate both near term requirements such as Space Station assembly, and longer term objectives for reduced space transportation costs.

The Shuttle-C study focuses on the early heavy lift capability making maximum use of existing shuttle systems in order to minimize vehicle development cost and schedule risk, and to assure payload compatibility with the existing space shuttle payload environment. If cost effective, such a vehicle could be used to launch planetary missions and serve as an unmanned test bed for new shuttle boosters.

The Shuttle-C would be able to lift 100,000-150,000 pounds into orbit compared to the space shuttle's design capacity of 65,000 pounds.

The availability of such a vehicle for Space Station assembly would free the space shuttle for increased work in all the sciences - solar system exploration, astronomy, life sciences, and materials processing experimentation. Progress in all these areas was severely constrained by the Challenger accident, and there is a pressing need for the nation to catch-up, according to numerous studies.

To manage the Shuttle-C study, a task team was established at MSFC under the Heavy Lift Launch Vehicle Office, headed by Mr. T.J. (Jack) Lee, the Deputy Center Director of MSFC. Mr. Glenn Eudy was designated Manager of the Shuttle-C Task Team. The team is staffed with senior MSFC personnel.
In the course of national planning for future space missions and
design of payloads, the need to identify requirements and define
a highly reliable heavy lift cargo vehicle has become evident.
The operational concept is to use an unmanned cargo element
(CE) when a heavy lift capability is required. The vehicle is
required to provide, as a minimum, (1) flexibility and high
reliability for missions such as Space Station assembly,
logistics support and planetary missions; (2) capability to
serve as a test bed for new launch systems as they are developed
such as the Space Transportation Booster Engine (STBE) and Space
Transportation Main Engine (STME), Advanced Solid Rocket Motor
(ASRM), Liquid Rocket Booster (LRB) for the shuttle, and
cryogenic upper stages; and (3) satisfy the needs of the Civil
Space Program.

The Shuttle-C shall be defined around maximum use of the
existing/developed shuttle and other systems, facilities and
technology to assure high reliability, low risk, early
availability, and to minimize design, development, test and
evaluation (DDT&E) costs. Advantage shall be taken of the
existing shuttle operations to enhance operating efficiencies,
thereby further reducing costs. This vehicle shall make
extensive use of the existing National Space Transportation
System (NSTS) hardware elements, facilities, and operational
capabilities.

Many of the payloads planned for this vehicle are unique,
costly, require long manufacturing times, and are critical for
the Civil Space Program. The Shuttle-C may also later be
required to launch manned Crew Emergency Return Vehicles
(CERV's) to retrieve stranded or disabled Space Station or
shuttle crews. Such a payload mixture requires extremely high
reliability, so the Shuttle-C cargo element must be designed and
developed in accordance with manrated criteria.

Definition Studies

In November 1987, NASA awarded definition study contracts to
three contractor teams to define a recommended Shuttle-C
concept, vehicle configuration, and preliminary design
requirements for a potential FY 1989 new initiative for the
agency. The prime contractors for these definition study teams
are Martin Marietta Corp., United Technologies Corp., and
Rockwell International.

The contracts are divided into two parts: Basic contract period
(phase-I), comprising the first four months of activities; phase
II consisting of a negotiated option covering the remaining five
months of the contract period. The initial month of the basic
contract period was to be a concentrated effort to establish the
requirements for the overall vehicle, major systems elements and operations. Two months after contract start, a concept determination was to be made between inline and sidemount versions of the cargo element. The next two (2) months were to be devoted to trades and analyses of various configurations, ending with one configuration being recommended for definition during the option period of the contract.

Reference Vehicle Configuration

Several alternative vehicle designs for Shuttle-C were assessed by NASA. These included inline and sidemounted vehicle configurations of various dimensions, as well as hybrid configurations. Analyses of these alternative designs were continued by the Definition Study Contractors, leading to a final recommended configuration in early 1988.

Preliminary in-house analysis indicated that the sidemounted concept was the preferred approach. For this reason, a baseline reference vehicle was developed by NASA which consisted of a sidemounted expendable payload carrier; two standard 4-segment reusable solid rocket boosters (SRB's); a standard expendable external tank (ET); a modified orbiter boattail with the vertical stabilizer and body flap removed, containing two space shuttle main engines (SSME's), two orbital maneuvering systems (OMS) pods, and reaction control system (RCS) thrusters, (to perform orbital circularization and deorbit); and associated avionics from STS and other mature vehicle design applications.

The payload carrier has a usable payload space of 15 feet diameter by 72 feet in length. The canister is of skin/stringer/ringframe construction with a new strongback and payload shroud. (Reference figure 1).

The payload capability for this reference configuration is 103,000 pounds to 220 nautical miles (NM) at 28.5 degrees inclination (Space Station orbit) or 114,000 pounds to 160 NM.

The ascent phase of Shuttle-C flight will be autonomously controlled by systems onboard the vehicle. Once in orbit, flight/mission operations will be controlled via an attached orbital maneuvering vehicle (OMV), which will either rendezvous and dock with the Shuttle-C, or be carried up with it as part of the payload. This will permit control of the Shuttle-C from either the ground or the Space Station, for proximity operations near the station.

Deorbit of the payload carrier to a safe ocean impact point will be conducted either autonomously or via the OMV from the ground.
Synergistic Benefits to Space Shuttle Program

The potential synergistic benefits of Shuttle-C development and operations on the space shuttle program has been assessed. A discussion of these benefits follows:

Shuttle-C is being designed to provide a compatible and complementary launch capability with the STS. A goal of Shuttle-C is to minimize DDT&E costs. In order to accomplish this, Shuttle-C design philosophy will make maximum use, to the extent practical, of shuttle hardware, including common SRB’s, common ET’s, common ET-to-payload carrier interfaces, and common shuttle ground processing facilities: VAB, OPF, launch pad, mobile launcher, launch control center, etc. Shuttle-C will also be capable of carrying all shuttle payloads. As a goal the vehicle is designed to make use of existing shuttle systems, procedures, software, avionics, checkout and launch facilities, personnel, etc., which will enable DDT&E and operating costs to be held to a minimum. This approach should achieve maximum synergistic benefits to both programs through the use of common interfaces, engineering drawings, and other engineering documentation.

In order to ensure an operations philosophy which is compatible with and complementary to STS, NASA has developed with in-house resources, a Shuttle-C Operations Concept Plan. This plan addresses all aspects of Shuttle-C ground and flights operations, vehicle configuration, design reference missions, mission scenarios, operational requirements, management concepts, and operations planning. It covers such subjects as vehicle processing, facility utilization, software production, rendezvous and proximity operations, etc. Elements of this document relating to design reference missions and operational requirements were furnished to the definition study contractors for use in their analyses.

Shuttle-C development and operations will be managed such that it will not adversely effect space shuttle recovery activities and flight schedules. Shuttle-C, as currently envisioned, uses a cargo element which is similar to an STS orbiter, simplified by removing the features required for life support, extensive orbital operations, flyback, and landing. Other primary elements such as the solid rocket boosters and external tanks are intended to be identical to those used by the shuttle. This high degree of commonality with the shuttle presents an opportunity to capitalize on existing shuttle resources.

Prudent design of Shuttle-C will permit the use of existing and planned STS ground processing facilities with minimal operational impact. Existing and planned launch complex 39 facilities can accommodate a launch rate of about 14 STS flights per year. A combined STS and Shuttle-C flight rate of more than
14 flights per year will probably require a new SRB stacking facility and an additional mobile launch platform (MLP).

The reference sidemount Shuttle-C vehicle will be integrated in the Vehicle Assembly Building (VAB) high bay, following checkout of the cargo element in the VAB low bay. For the reference vehicle (two-engine/sidemount) configuration, the VAB is moderately impacted (primarily access platforms), and minor modifications will be required for the MLP, launch pads, and payload systems. These modifications will be accomplished without impacting support to shuttle, while also maintaining existing shuttle vehicle interfaces.

The Shuttle-C will use the existing launch processing system (LPS). Compatibility will be achieved by using the same hardware or by using interface hardware to provide compatibility. This requires that Shuttle-C be compatible with existing LPS hardware/software; that Shuttle-C and STS avionics are compatible; and that data tape, mass memory loads, and telemetry formats are compatible between Shuttle-C and STS.

Preliminary in-house estimates indicate that the Shuttle-C integrated vehicle processing can be accomplished in the equivalent or less time, as the processing time for the shuttle vehicle. ET and SRB stacking operations will be similar to shuttle operations, and mating to the cargo element is similar to mating to the shuttle orbiter. Pad operations for the Shuttle-C should be equivalent or somewhat simpler than shuttle due to reduced interface verifications.

More extensive facility modifications would be required for vehicle configurations other than the reference (two-engine/sidemount). Additional operations and facilities studies will be conducted under the vehicle definition studies.

With respect to the use of expendable space shuttle flight elements/systems, the following observations can be made: Prior to the Challenger accident, NASA had planned for sufficient ET and SRB production capability to accommodate up to 24 shuttle flights per year. There is, therefore, sufficient production capability for ET's, SRB nozzles, and flight systems to accommodate the two to three anticipated Shuttle-C flights per year.

In addition to serving as an alternate launch capability, the Shuttle-C would provide three major benefits to shuttle: An unmanned flight test bed for new or enhanced shuttle capabilities and advanced systems; reduced unit costs from increased production rates; and increased transportation resiliency from the combination of the two systems.
Several propulsion enhancements are under study as improvements to the shuttle including the advanced solid rocket motor (ASRM), the liquid rocket booster (LRB), which would replace the solid rocket booster (SRB), and possibly new liquid engine systems. Although these systems would be designed for high reliability, use of the unmanned Shuttle-C vehicle for the initial flight would give added confidence, and demonstrate performance without any risk of human life.

A second benefit from Shuttle-C is that the increase in production rates of STS common components (e.g., engines, computers) will reduce unit costs. In some areas, such as avionics, there is also the potential of losing shuttle subcontractors because of the low production rates, which may be alleviated by Shuttle-C needs.

The use of a mixed Shuttle/Shuttle-C fleet is also expected to provide increased transportation resiliency. A parametric study is currently underway which will provide an analysis in terms of resiliency (the probability of satisfying flight rate requirements), availability (fraction of the time operational), mean time to failure risk, surge capability, and cost effectiveness.

Benefits to Space Station and Other Programs

NASA has assessed the benefits and cost-effectiveness of the Shuttle-C for the Space Station and other NASA programs, and whether these benefits could also be obtained with the current or improved expendable launch vehicles (ELV’s) or other ALS versions. The next portion of this paper discusses these assessments.

The use of the Shuttle-C concept could benefit the Space Station Program in several ways. The Shuttle-C concept provides the capability to launch fully integrated Space Station modules. It provides a reduction in the total number of flights needed to achieve permanently manned operational capability, and it provides a large logistics capability.

Launching fully integrated Space Station modules with the Shuttle-C would reduce the need to integrate the modules on orbit during assembly. For example, the fully integrated Space Station lab module estimated at 69,300 pounds would require 29,800 pounds of hardware to be offloaded prior to launch on the shuttle. Such hardware would then be launched on additional shuttle flights, installed, and integrated on orbit. With Shuttle-C, the fully integrated 69,300 pound lab module could be launched on one flight thereby reducing EVA/IVA time and enhancing reliability.
The Shuttle-C concept of compatible interfaces with shuttle provides flexibility in Space Station launch packaging by its increased volume and weight capability. The recent Space Station Transportation Studies identified, for example, how the number of STS flights could be reduced from 19 to 7 by adding five Shuttle-C flights. The assembly period time-span could be reduced, if desired, from the present 36 months to as little as 18 months. The number of launch package end items to be assembled on orbit is reduced from 45 to 34. Phase I assembly could thus be completed several months earlier than with the STS alone and with a net reduction of 7 flights and no changes in Space Station design. The Shuttle-C would provide significant increased flexibility and robustness in schedule and weight margin for station assembly. For example, because of the inherent large payload capacity of Shuttle-C, late hardware articles could be delivered to the station as an aggregate payload on one Shuttle-C. This resiliency could permit the compression, or catch-up, of the assembly schedule that may not be feasible with the shuttle alone. Slips in hardware manifested for Shuttle-C could be accommodated without a large remanifesting effort for subsequent STS launches.

The current baseline for Space Station resupply required annual delivery weight of approximately 180,000 pounds, including crew rotation and logistics. With 103,000 pounds of payload capability to the Space Station, Shuttle-C could help accommodate resupply requirements (except crew rotation).

Studies are also underway to investigate the feasibility of launching the crew emergency return vehicle (CERV) on the Shuttle-C.

Benefits to Other NASA Programs

The Shuttle-C could benefit several proposed new initiatives and planned programs. Shuttle-C would provide design options to payloads now planned for manifesting on smaller and more constraining vehicles. The extra payload margin could be used to carry additional scientific instruments or to make cost trades.

The projected Shuttle-C capability could place 56,000 pounds in sun-synchronous orbit (445 NM/98.7 degrees) or 20,000 pounds in geo-sync orbit (22,000 NM) using a Centaur upper stage adapted for Shuttle-C. Polar platforms and other payloads not requiring crew interaction could be offloaded to Shuttle-C. Shuttle-C would also allow the launch of co-orbiting platforms on the same launch vehicle. It would assure alternate launch capability for all Titan/Centaur class payloads.

NASA has examined use of the Shuttle-C for several planned planetary exploration missions, including the Comet Rendezvous
Asteroid Flyby (CRAF) - the first of the planned Mariner Mark II missions - Cassini (the second planned Mariner Mark II mission), and the Mars Rover Sample Return (MRSR). CRAF is proposed as a new start for FY89 and it is currently planned for launch on a Titan IV/Centaur.

The benefit of the Shuttle-C/Centaur G-Prime for any of these missions derives from the fact that the Shuttle-C can deliver the spacecraft and a fully loaded Centaur to low earth orbit. This is a significant improvement over the current Titan IV, wherein approximately one-third of the Centaur propellants are expended in order to achieve the initial parking orbit.

Additional performance provided by the Shuttle-C allows added mission and spacecraft system flexibility and permits tradeoffs of one or more of the following to enhance the mission:

- Extended observation time.
- Additional flexibility in the selection of scientifically interesting targets.
- Additional spacecraft propellant for operations and maneuvers and/or additional satellite encounters.
- Increased payload mass to enable addition of other science instruments.
- Shorter trip time.

Shuttle-C offers a significant advantage for the MRSR mission by launching the rover orbiter, ascent and descent systems, and sample return vehicle in a single launch as opposed to the requirement for two separate launches if the Titan IV/Centaur were used.

Cost Benefits of Shuttle-C

Another benefit of a Shuttle-C mixed fleet derives from its overall reduction in cost per flight over alternate launch vehicles. Some of the preliminary estimated trends are discussed below.

An analysis was performed of launch vehicle operations cost estimates comparing the cost per pound to 160 NM of various existing and planned launch systems. All existing and planned expendable systems exhibit higher operations cost than the projected marginal costs associated with Shuttle-C.

An analysis was also conducted of life cycle cost comparison of Shuttle-C versus interim ALS taking into account both DDT&E and operations costs and comparing the resulting life cycle costs of
Shuttle-C and a representative interim ALS concept over a range of cumulative pounds of payload to orbit. The Shuttle-C projects lower DDT&E requirements than the representative interim ALS concept and lower operational cost for the same mission model. For a projected 3 million pounds to orbit (corresponding to 27 Shuttle-C and 32 ALS flights, respectively), Shuttle-C has undiscounted life cycle costs of only about two-thirds of the life cycle costs associated with the representative concept.

The projected Shuttle-C launch marginal cost per payload pound is substantially lower than any available ELV. The ALS program goal of reducing launch costs of the objective ALS by a factor of 10 would make the ALS more cost effective at higher flight rates, but until the ALS is available in the late 1990’s, the Shuttle-C would be the most cost effective means of launching large unmanned payloads.

**Conclusion**

The Space Transportation Architecture Studies (STAS), which were jointly funded by NASA/Air Force/Strategic Defense Initiative Organization, evaluated hundreds of potential vehicle systems to satisfy the projected launch requirements of the 1995-2020 timeframe. One of the major study conclusions included introduction of a heavy lift cargo capability by 1995. Key design goals for this system included: a payload capability in the 100-150K pounds range, very high reliability, flexibility and robustness, and substantially reduced operating costs. Other NASA studies have concluded that a shuttle derived heavy lift launch capability could help satisfy total national launch requirements in the mid-1990’s and that if such a capability were available it could be used to support Space Station assembly.

The NASA/DOD STAS focused on approaches to meet the mission objectives while at the same time striving to achieve significant cost reductions. These studies have concluded that significant cost reductions can only be obtained by incorporating new technologies and design considerations in the vehicle and operational concepts. However, it takes time to develop these new technologies. Hence, there is no single vehicle option which can simultaneously satisfy both major goals: (1) early operational availability, and (2) significant cost reductions.

Therefore, NASA’s approach for the nearterm is to develop the Shuttle-C to meet those heavy lift launch requirements beginning in the 1994 timeframe. This would provide a very credible and reliable nearterm solution for large payloads. Since it would be built on largely existing flight-proven hardware, the
front-end development costs would be much lower than other vehicle options.
SHUTTLE-C
SIDE-MOUNT CONFIGURATION

- STANDARD 4-SEGMENT SRB'S (REUSABLE)
- STANDARD ET (EXPENDABLE)
- ORBITER BOATTAIL (EXPENDABLE)
  - 2 SSME'S (REMOVE SSME #1)
  - REMOVE VERTICAL STABILIZER
  - REMOVE BODY FLAP
  - CAP SSME #1 FEEDLINES
  - OMS PODS (DO NOT INSTALL OME'S, RCS TANKS AND 4 RCS THRUSTERS/POD)
  - RCS PERFORMS CIRCULARIZATION AND DEORBIT
  - COVER AND THERMALLY PROTECT SSME #1 OPENING
- PAYLOAD CARRIER (EXPENDABLE)
  - NEW SHROUD/STRONGBACK
  - SKIN/STRINGER/RINGFRAME CONSTRUCTION
  - 15'D X 72'L USABLE PAYLOAD SPACE
  - SPRAYABLE LOW TEMPERATURE ABLATOR
  - INTERNAL ACOUSTIC/THERMAL INSULATION
- AVIONICS
  - USES MATURE DESIGN COMPONENTS FROM STS TO MAXIMUM EXTENT PRACTICAL
  - REQUIRES SOME NEW INTEGRATION AND SOFTWARE

FIGURE 1