EARTH-TO-ORBIT TRANSPORTATION FOR SOLAR POWER SATELLITES

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Transportation of solar power satellites to space will require cargo transport capability much greater than any other space technology application thus far investigated. The cost of space transportation operations represents, in the reference SPS system, more than one fourth of the total production cost of the SPS's, even though the unit cost in dollars per kilogram is projected to be much less than that presently foreseen for the Space Shuttle. Three-fourths of the cost is contributed by the launch systems (including launches delivering orbit transfer propellant) with the remainder contributed by orbit transfer systems. Further, developing the vehicles required and acquiring the operational vehicle fleet is the largest single element of SPS nonrecurring cost. Consequently, the design approach for these vehicles and their ability to achieve the projected cost is of great importance to the economic practicality of solar power satellites; commensurate importance has been given to the concept definition for space transportation in the SPS Systems Definition studies.

The history of SPS launch vehicle evolution is shown in Figure 1. Early studies of SPS launch vehicles examined ballistic systems shaped like large Apollo spacecraft; these were to return to Earth engines-first by aerobraking and land at sea for recovery by ship. Single-stage and two-stage options were examined. The performance of the two-stage systems was enough better to more than offset their greater operational complexity.

Later, comparison of winged and ballistic launch vehicles concluded that the winged systems were preferred. Although more expensive per unit, shorter turnaround time permits a smaller vehicle fleet, effecting overall savings. This trade resulted in selection of the two-stage winged vehicle now represented as the SPS reference launch vehicle. The size of the vehicle was somewhat arbitrary. The only specific consideration was selection of a payload bay large enough to accommodate a fully-assembled electrical slip ring, 16 meters in diameter. The payload capability of the reference vehicle was estimated as 420 gross tonnes, with an effective net payload of about 360 to 380 tonnes after accounting for mass of payload pallets, propellant containers, and similar factors.

This vehicle design was based on "normal" technology growth. The second stage engine was the Space Shuttle Main Engine (SSME) and the first stage engine was assumed to be a new-development gas-generator oxygen-hydrocarbon engine. Modest use of composite materials in the dry structure was assumed, limited to areas not subjected to high temperatures as a result of aerodynamic or plume heating. The booster is a heat-sink design for reentry heating; the orbiter assumes an advanced Shuttle-type RSI, with improved durability and serviceability. Subsystems masses were based on extrapolations from the Shuttle subsystems. The reference vehicle is shown in Figure 2. Figure 3 presents a mass distribution, and Figure 4 shows the corresponding first unit cost. Figure 5 shows the schedule estimates for vehicle turnaround upon which the fleet size is based.

Alternative vehicle designs have been created by other studies. The most important are (1) A parallel-burn, crossfeed configuration developed by Rockwell International on their SPS studies; (2) A single-stage-to-orbit airbreathing/rocket runway takeoff vehicle concept developed by Rockwell, and (3) A smaller HLLV concept developed by Boeing. The parallel-burn configuration yields about 10% improvement in payload capability at a given liftoff mass, but involves increased operational complexity. An adequate tradeoff to select between series and parallel burn has not been conducted. The airbreather concept was representative of vehicle designs that might be attainable with highly advanced propulsion and structures technology.

The smaller HLLV was analyzed to compare the non-recurring cost benefits of a less challenging development with the recurring cost increases expected due to losses in efficiency associated with smaller vehicle size. The vehicle payload bay size was selected to be adequate to accommodate the SPS transmitter subarrays fully assembled. This required a square cross-section of 11 meters; the length was set at 14 meters. Paramentric investigations led to a gross lift capability requirement of 120 metric tonnes. The resulting vehicle design is compared with the Shuttle, the Saturn V, and the reference SPS HLLV in Figure 7. Mass estimating revised the parametrically-estimated lift capability to 125 tonnes. Costs were derived by the Boeing Parametric Cost Model (PCM), and cost per flight was estimated by procedures consistent with those used for the reference system. Operational effects of the smaller payload bay were analyzed to develop a total delta cost understanding. Delta environmental effects were also estimated. The end result was that a nonrecurring savings of at least five billion dollars was obtained with a recurring cost penalty of 3% per SPS. Further, the environmental benefits of the small vehicle: reduced sonic overpressure, noise, potential blast effect in the event of an accident, and less modification of the Cape Canaveral area to accommodate launch pads, were deemed more important than the slight increase in upper atmosphere propellant deposition. As a result of these considerations, it is recommended that the small HLLV be adopted as the SPS reference launch system.

Important areas remaining to be investigated include: (1) Comparison and selection between series and parallel burn; (2) Configuration development to a sufficient level of detail to permit specific facilities and operations systems definition; and (3) Development of an evolutionary strategy for evolving from the present Shuttle system, through Shuttle improvements or Shuttle-based interim HLLV capability, to the SPS operational configuration. Considerations include engine and subsystem commonality and evolution as well as launch capability to support SPS development requirements as well as other space applications needs.

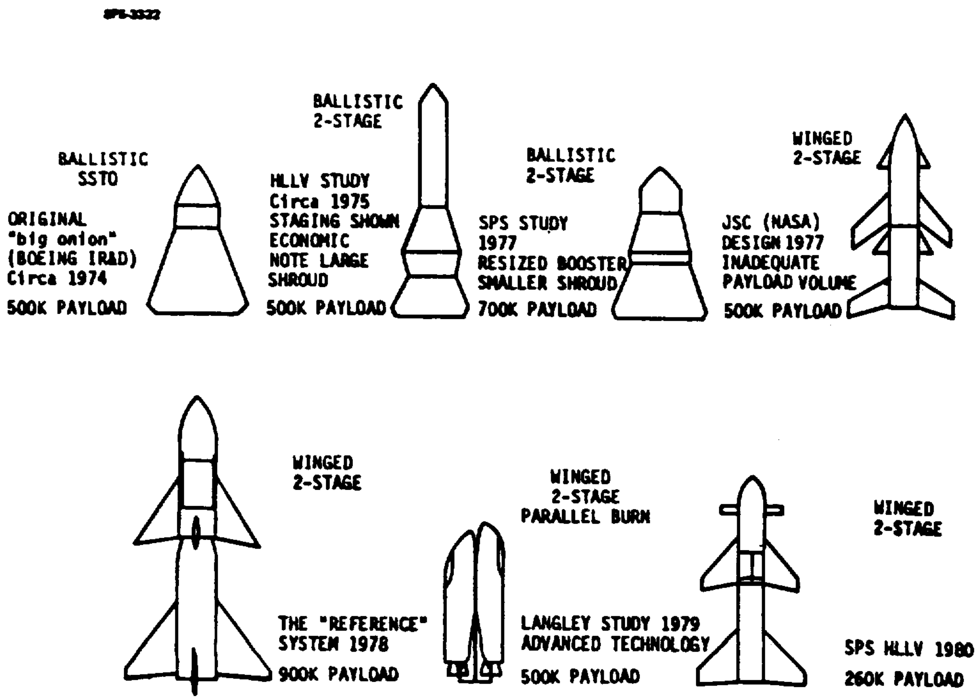
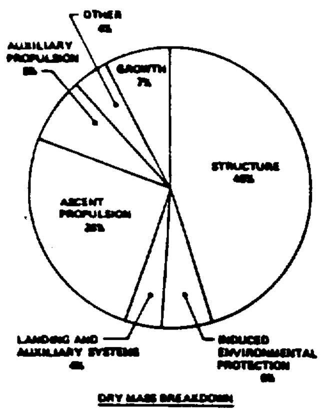
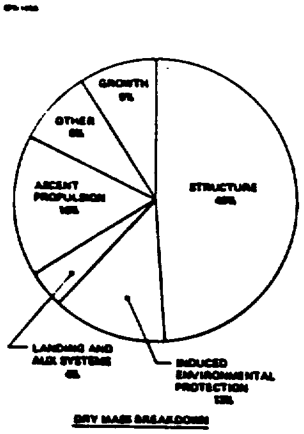


Figure 1- SPS LAUNCH VEHICLE CONCEPT EVOLUTION



	MASS (kg)
STRUCTURE	300 000
INDUCED ENVIRONMENTAL PROTECTION	46 400
LANDING AND AUXILIARY SYSTEMS	34 000
ASCENT PROPULSION	204 000
AUXILIARY PROPULSION	60 000
PRIME POWER	4 300
ELECTRICAL CONVERSION AND DISTRIBUTION	4 300
HYDRAULIC CONVERSION AND DISTRIBUTION	16 000
SURFACE CONTROLS	10 300
AVIONICS	1 000
ENVIRONMENTAL CONTROL	300
GROWTH	50 000
DRY MASS =	706 000
RESIDUALS AND RESERVES	40 000
LANDING MASS =	846 700
LOSSES DURING FLYBACK	36 300
START FLYBACK MASS =	883 000
ENTRY IN-FLIGHT LOSSES	3 700
START ENTRY MASS =	886 000
IN-FLIGHT LOSSES PRIOR TO ENTRY	27 000
STAGING MASS =	[illegible]
THRUST DECAY PROPELLANT	14 500
INERT MASS =	[illegible]

Figure 2- BOOSTER MASS STATEMENT



	MASS (kg)
STRUCTURE	138 000
INDUCED ENVIRONMENTAL PROTECTION	40 300
LANDING AND AUX SYSTEMS	16 000
ASCENT PROPULSION	50 000
AUXILIARY PROPULSION	8 600
PRIME POWER	3 000
ELECTRICAL CONVERSION AND DISTRIBUTION	4 000
HYDRAULIC CONVERSION AND DISTRIBUTION	3 000
SURFACE CONTROLS	6 000
AVIONICS	2 400
ECLSS AND PERSONNEL PROV	3 000
GROWTH	22 900
DRY MASS =	272 200
PERSONNEL AND PAYLOAD ACCOMMODATIONS	4 100
RESIDUAL AND RESERVES	14 600
LANDING MASS =	291 000
ENTRY IN-FLIGHT LOSSES	3 400
START ENTRY MASS =	295 300
IN-FLIGHT LOSSES PRIOR TO ENTRY	30 000
INERT MASS =	[illegible]

Figure 3- ORBITER MASS STATEMENT

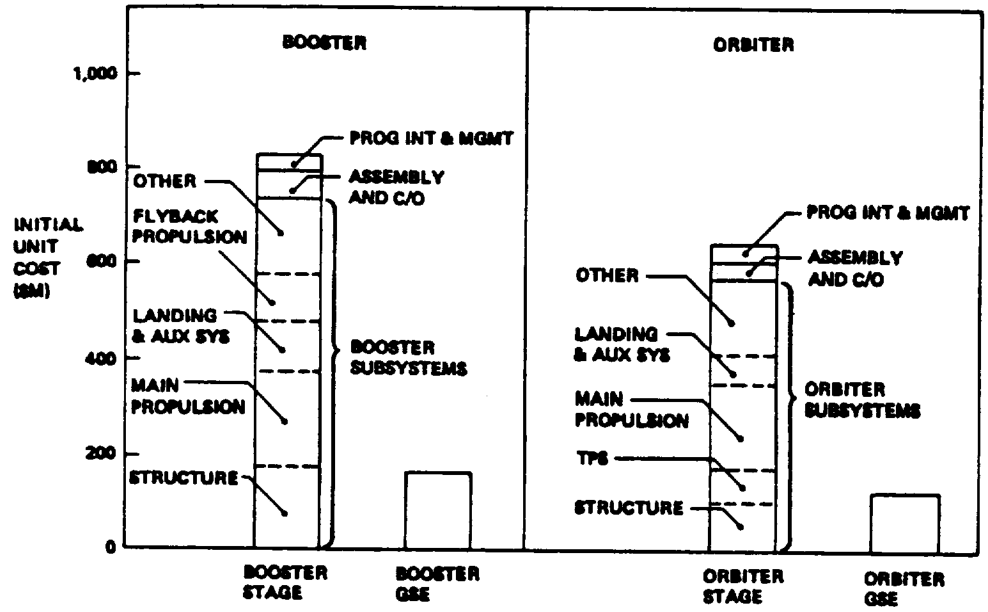


Figure 4- SPS LAUNCH VEHILCE PRODUCTION COST

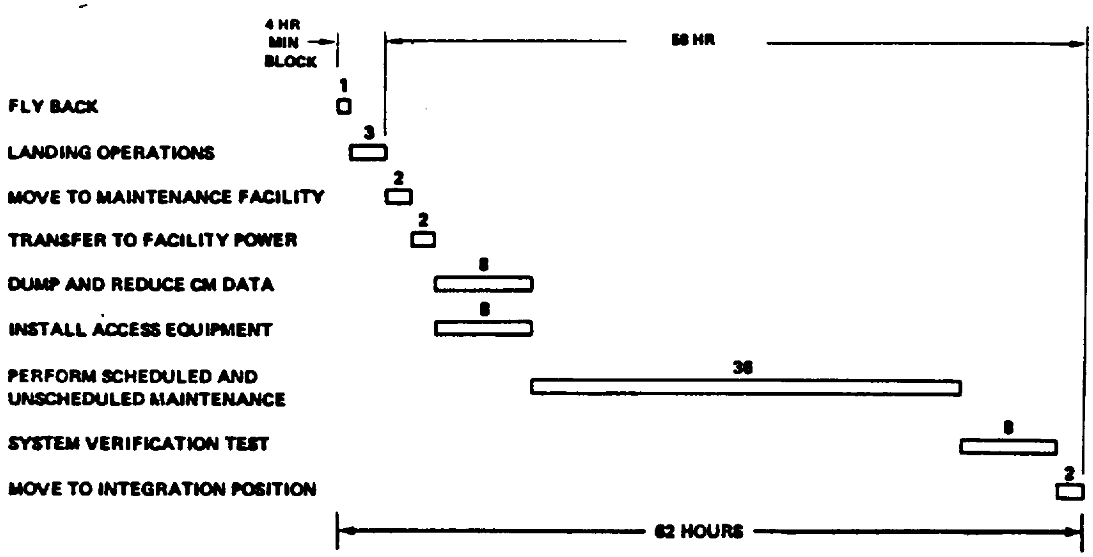


Figure 5- HLLV BOOSTER PROCESSING TIMELINES

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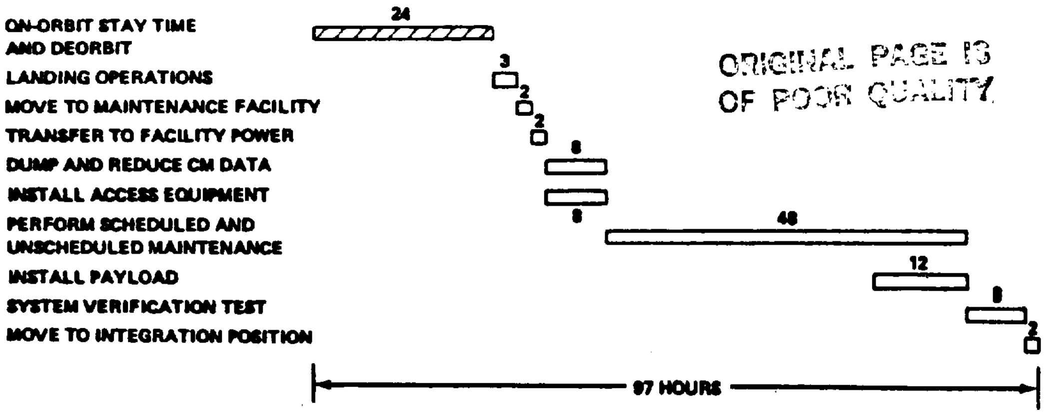

Figure 6- ORBITER PROCESSING TIMELINES

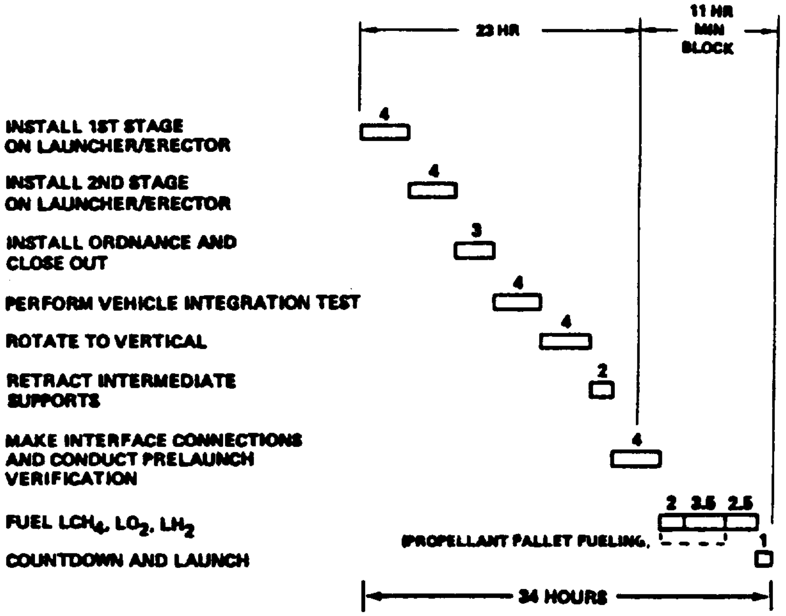

Figure 7- INTEGRATED VEHICLE OPERATIONS TIMELINES

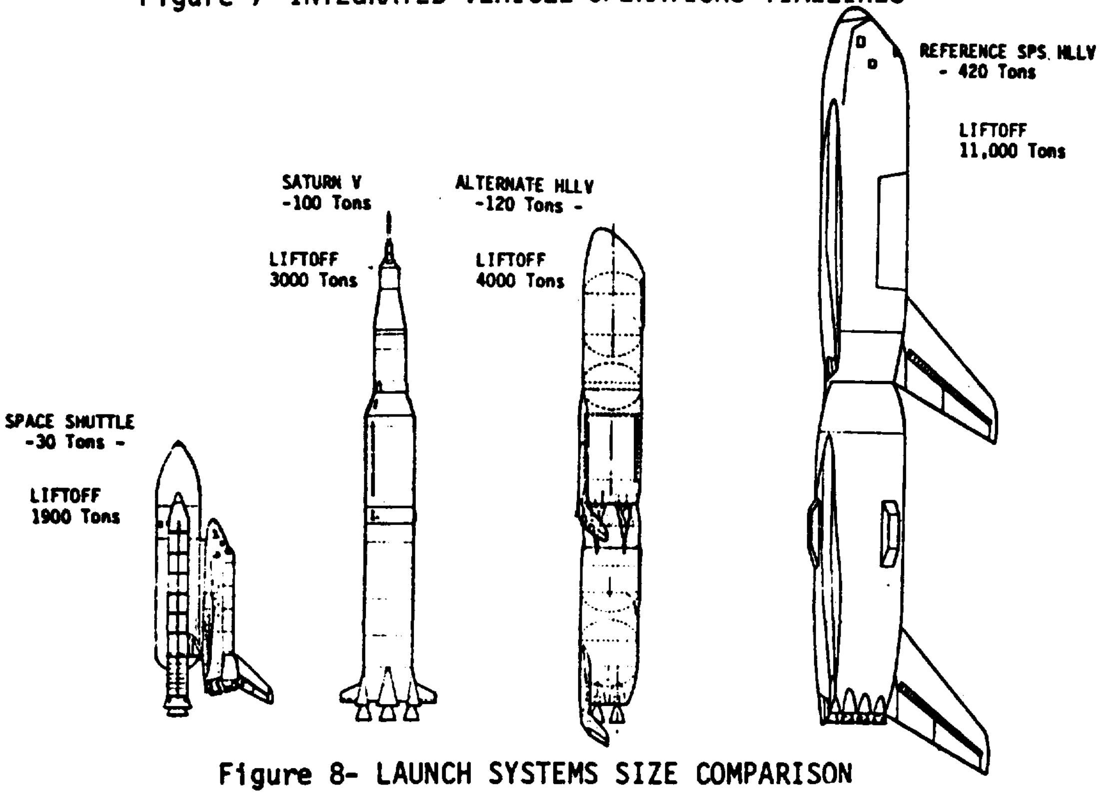

Figure 8- LAUNCH SYSTEMS SIZE COMPARISON