LOW-THRUST VEHICLE CONCEPT STUDIES

George R. Smolak
NASA Lewis Research Center

LOW THRUST VEHICLE CONCEPT STUDIES

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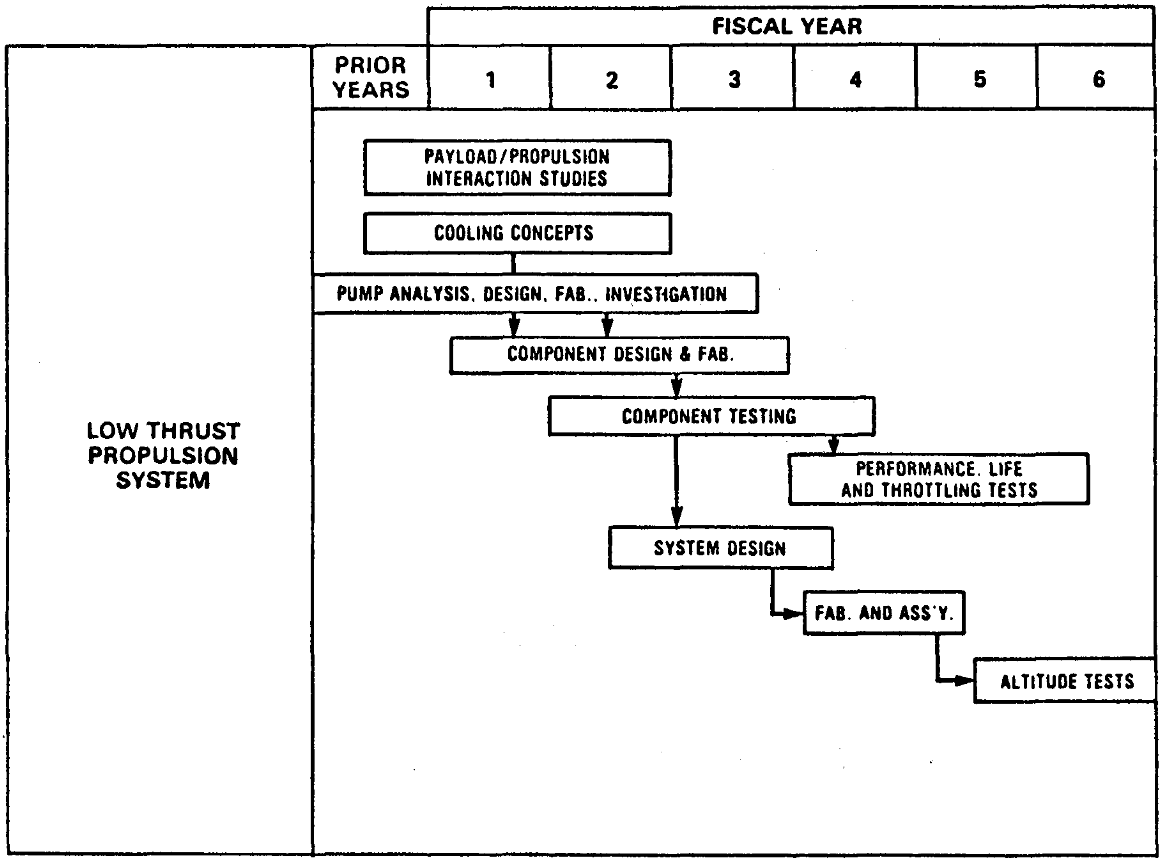
OBJECTIVES

- PROVIDE ANALYTICAL TOOLS TO DEFINE PROPULSION SYSTEM PERFORMANCE, WEIGHT, SIZE, ETC.
- DEVELOP PACKAGING CONCEPTS FOR LSS MISSION PROPULSION AND PAYLOAD SYSTEMS

ORBITAL TRANSFER VEHICLE PROPULSION SCHEDULE

The NASA Lewis low-thrust, vehicle concept studies are part of the NASA-OAST orbit transfer vehicle propulsion program. These studies are a portion of the effort identified as payload/propulsion interaction studies in the schedule chart. Dr. Priem addressed the overall schedule in his introductory remarks on the Low Thrust Propulsion Technology Program.

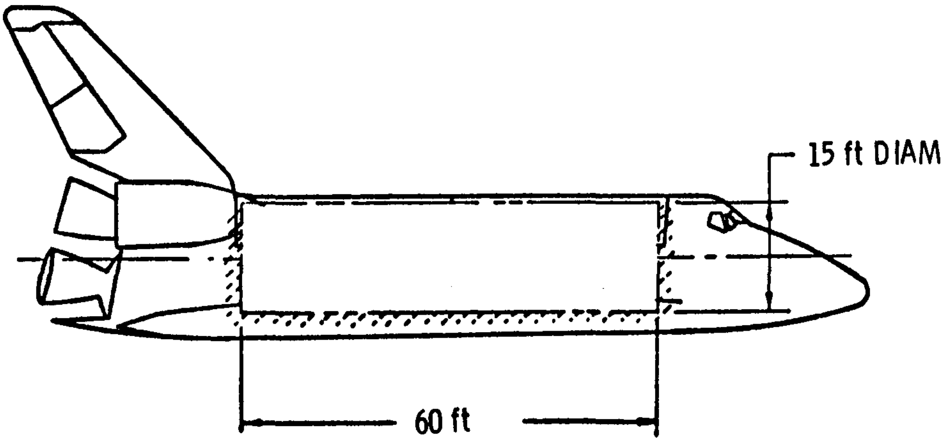
ORBITAL TRANSFER VEHICLE PROPULSION SCHEDULE



SHUTTLE CARGO BAY CONSTRAINTS

A number of Shuttle cargo bay constraints are important in the design of payload systems. The stowed vehicle (payload) must fit within the bay volume (15 ft. diameter by 60 ft. length) and must not exceed 65,000 pounds gross weight. Other major constraints arising from a ride in the Shuttle bay are; vibration, shock, acoustic and thermal environments and center-of-gravity location.

SHUTTLE CARGO BAY CONSTRAINTS

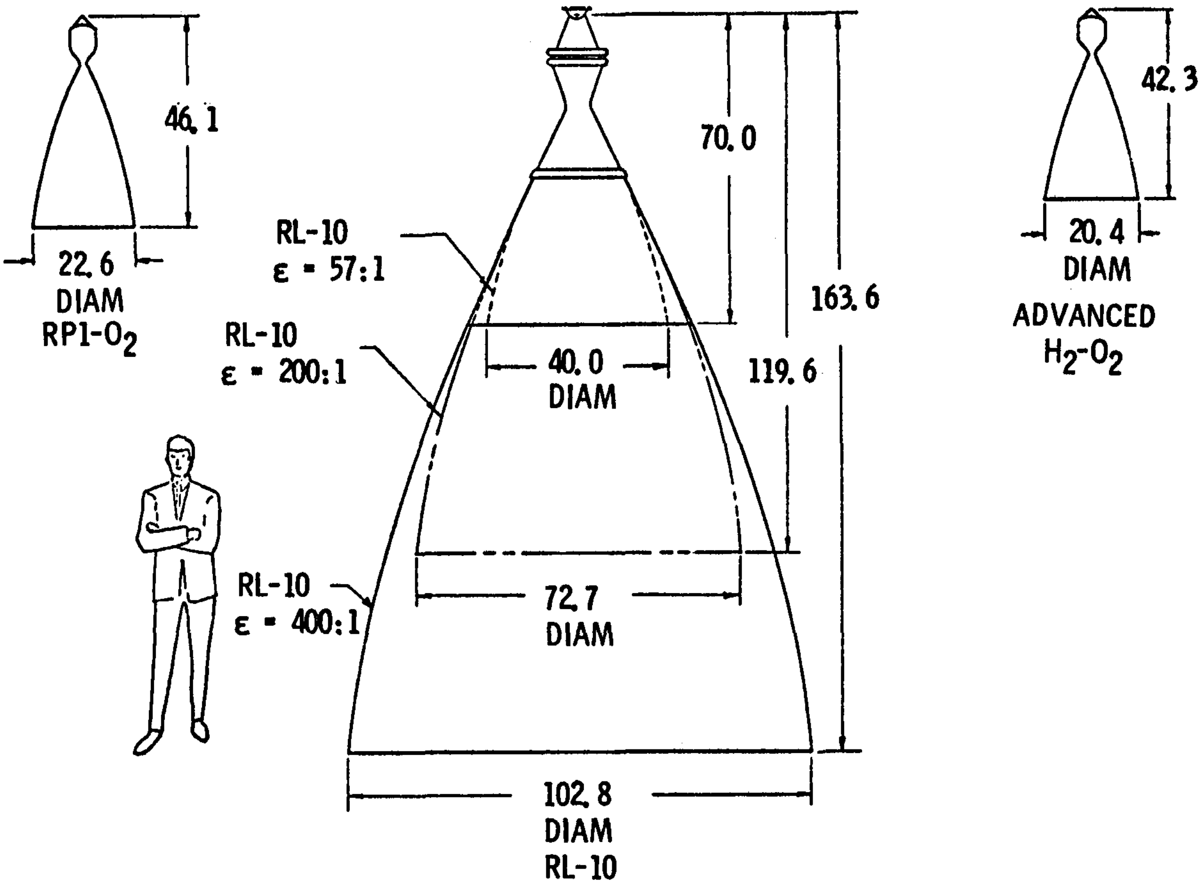


CARGO BAY LAUNCH WEIGHT CAPABILITY = 65 000 lb

APPROXIMATE SIZES OF LOW THRUST CHEMICAL ROCKET ENGINES

Additional constraints on the design of Shuttle payloads are imposed by the physical dimensions of typical low-thrust chemical rocket engines. The engine profiles include; (a) the Pratt and Whitney RL-10 (center sketch) with three different expansion ratio nozzles (57:1, 200:1, and 400:1). All dimensions on the chart are inches. The man shown is drawn to the same scale as the rocket engines. A large savings in engine length can be made if a significant length of the nozzle can be designed to retract. In the upper right portion of the chart is shown an advanced H_2-O_2 engine profile. A low thrust RP1-O_2 engine profile is shown in the upper left.

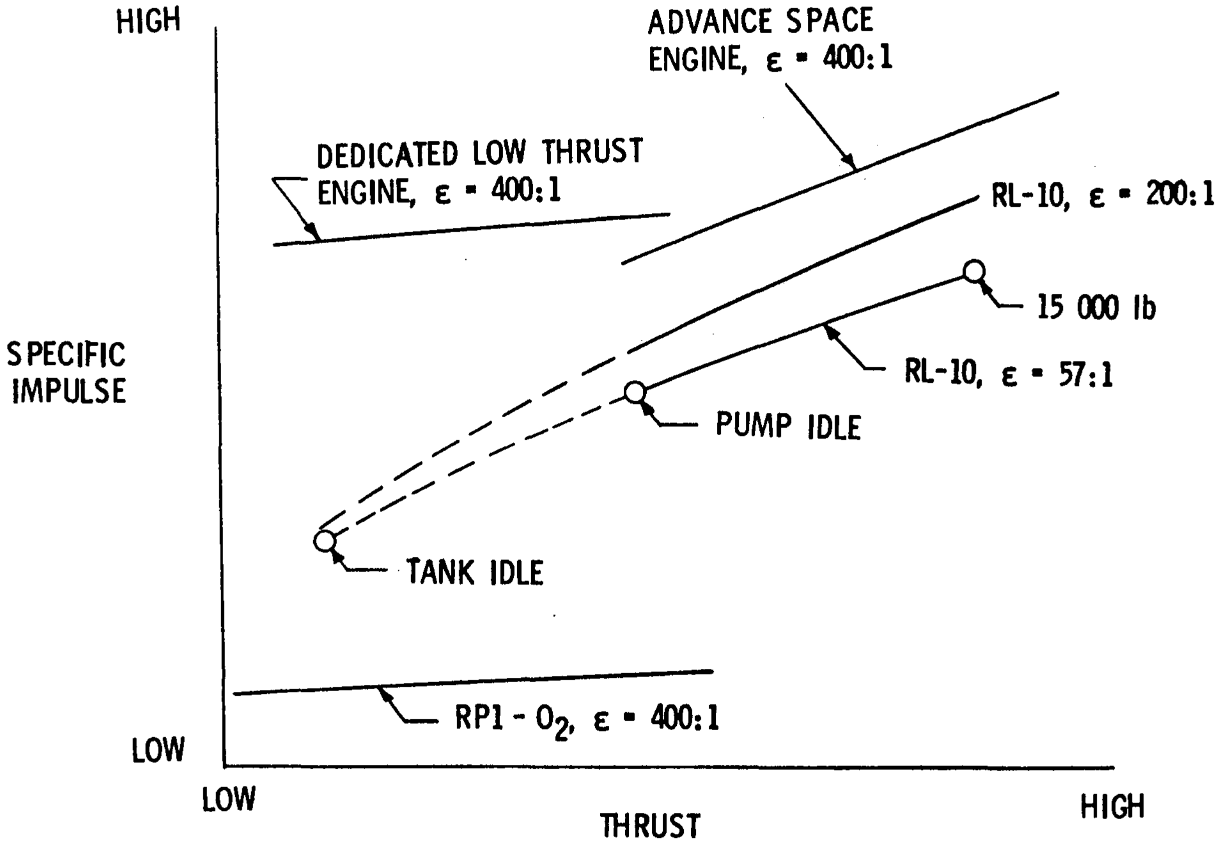
APPROXIMATE SIZES OF LOW THRUST CHEMICAL ROCKET ENGINES



RELATIVE PERFORMANCE OF VARIOUS ENGINES

This chart shows the relative performance of several candidate low thrust chemical rocket engines. Relative specific impulse is shown as a function of thrust for several engines (RL-10 family, Advanced Space Engine, dedicated low thrust H_2-O_2 engine, and RP1-O_2 engine). In its Centaur version, the Pratt and Whitney RL-10 engine produces 15,000 pounds of thrust. The same engine in idle modes produces much lower thrust (1500 pounds during pump idle mode and about 200 pounds during tank idle mode). However, the specific impulse is lower during idle mode operation. The Advanced Space Engine has a favorable high specific impulse, but its thrust is too high for "low thrust" missions. A dedicated low-thrust H_2-O_2 engine is needed. It should have a specific impulse almost as high as the Advanced Space Engine. The dedicated engine would thus offer a significant performance advantage compared to the RL-10 and RP1-O_2 engines.

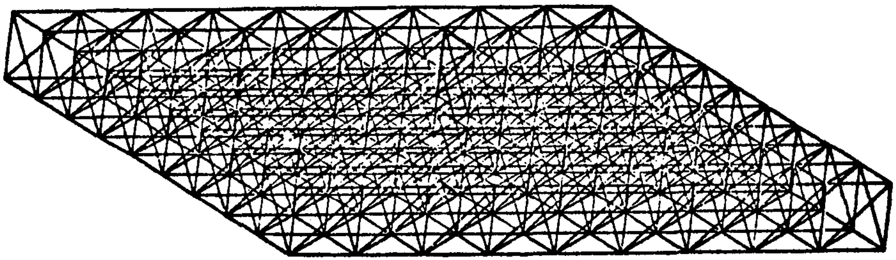
RELATIVE PERFORMANCE OF VARIOUS ENGINES



LARGE SPACE FRAME PLATFORM CONCEPT

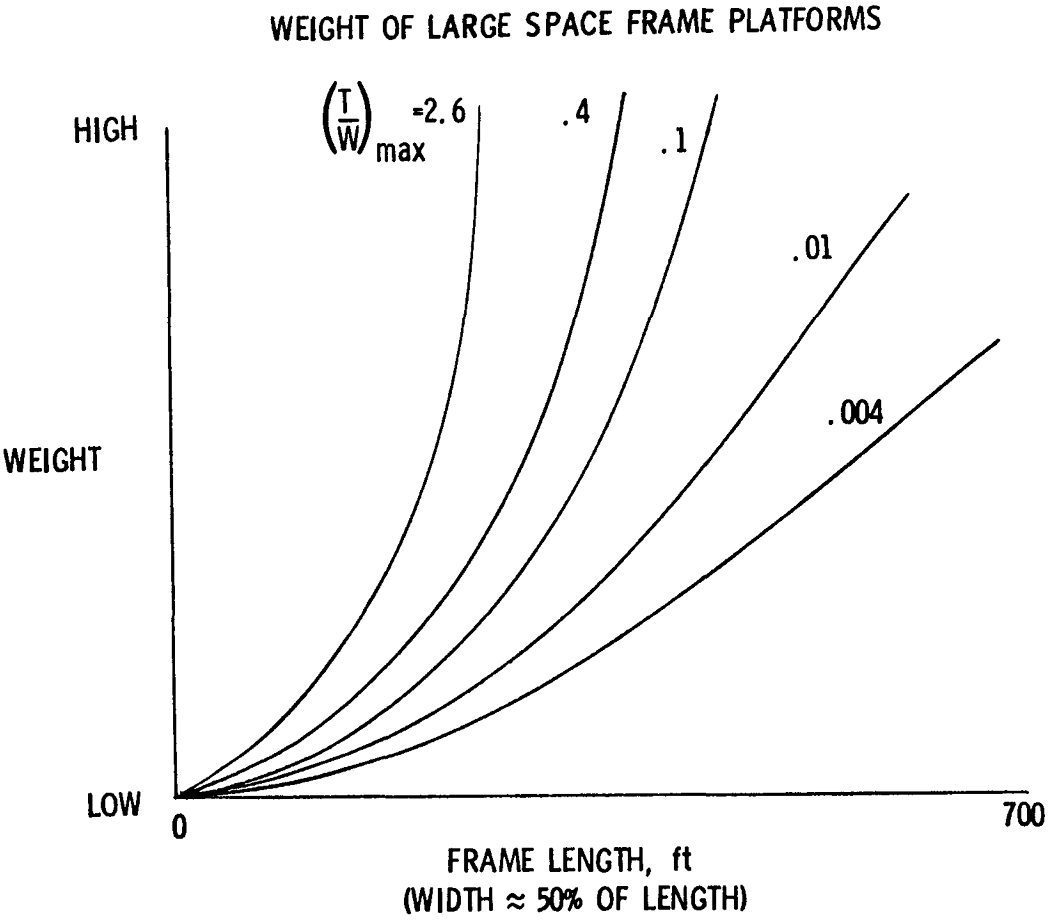
Many large space structures have been proposed in the literature. The large deployed space frame shown in the chart is typical of one family of these large structures. Dimensions of these structures generally run hundreds of feet in length and width and up to about 50 feet in depth. Since they are deployed from the Shuttle bay, the structures must be stowable. Materials generally proposed for these structures are epoxy-graphite thin wall tubes, joined by end fittings and wires.

LARGE SPACE FRAME PLATFORM CONCEPT



WEIGHT OF LARGE SPACE FRAME PLATFORMS

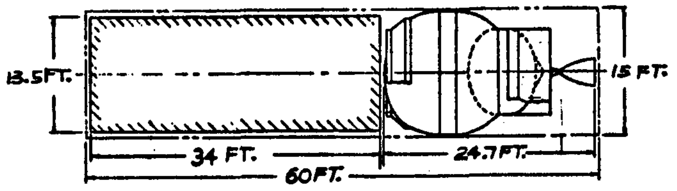
This chart shows the relative weight of deployed large space frames of the type shown in the previous chart. Frame weight is shown as a function of frame length for a variety of thrust-to-weight ratios. Frame width has been assumed equal to about 50% of frame length. For the desired frame lengths of many hundreds of feet, the chart indicates that the frame weight will be low for low thrust-to-weight ratios, but very high for high thrust-to-weight ratios. The weights shown are minimum for on-orbit control stiffness. Clearly, low thrust-to-weight ratios are desirable to maximize space frame deployed dimensions.



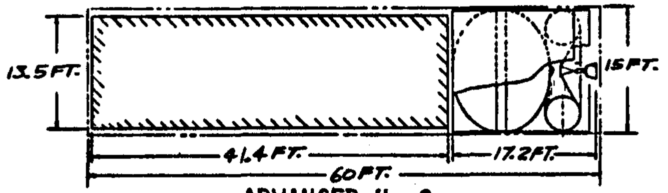
LSS SYSTEMS STOWED IN SHUTTLE BAY

The next chart shows a number of large space structure (LSS) systems (including propulsion systems) as they would appear when stowed in the Shuttle cargo bay. The four top configurations shown (large space frames with; modified Centaur using the RL-10 engine in the tank idle mode, advanced H_2-0_2 engine, RP1-0_2 engine and advanced H_2-0_2 engine with same space frame as RP1-0_2 engine) represent the results of recent NASA-Lewis in-house packaging studies. The goal of the studies was to design compact, light-weight propulsion modules having high specific impulse so that the volume available for the stowed space frame was maximized. Each of the top three LSS stowed systems has a 65,000 pound gross weight. The bottom configuration has the same LSS stowed system as the RP1-0_2 example but weighs less than 65,000 pounds. All of the stowed frames have a density close to 2.5 pounds per cubic foot. The system using the advanced H_2-0_2 engine has the largest space frame capability and the RP1-0_2 engine system has the least payload carrying capability. Each propulsion system was sized to raise its respective deployed payload from low earth orbit (LEO) to geosynchronous orbit in several days with several burns.

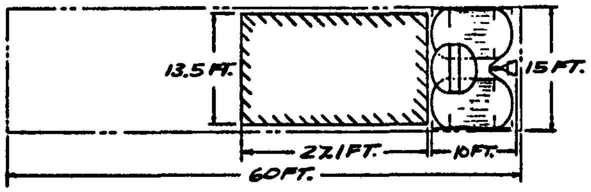
LSS SYSTEMS STOWED IN SHUTTLE BAY



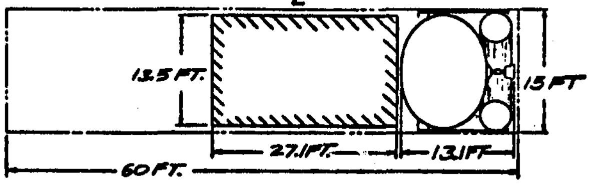
MODIFIED CENTAUR (RL-10, TANK IDLE MODE)



ADVANCED H_2-0_2



$RP1$-0_2



ADVANCED H_2-0_2 (SAME LSS AS RP1-0_2)

LSS PAYLOAD CAPABILITY

A comparison of deployed large space frame structures with specifications for their respective H_2-O_2 propulsion systems is shown in the next chart. The largest space frame (667 feet long by 360 feet wide by 41 feet deep) results from using the advanced H_2-O_2 (high specific impulse, low thrust) propulsion system. The smallest space frame shown results from using the Pratt and Whitney RL-10 engine in the pump idle mode. The associated high thrust-to-weight ratio (0.073) creates large stresses in the space frame members compared to a thrust-to-weight ratio of 0.01 for the other space frames in the chart. On the right hand side of the chart approximate space frame tube dimensions are shown for the maximum stress location in each tube. Graphite-epoxy tube materials were assumed with a minimum wall thickness of 0.015 inches.

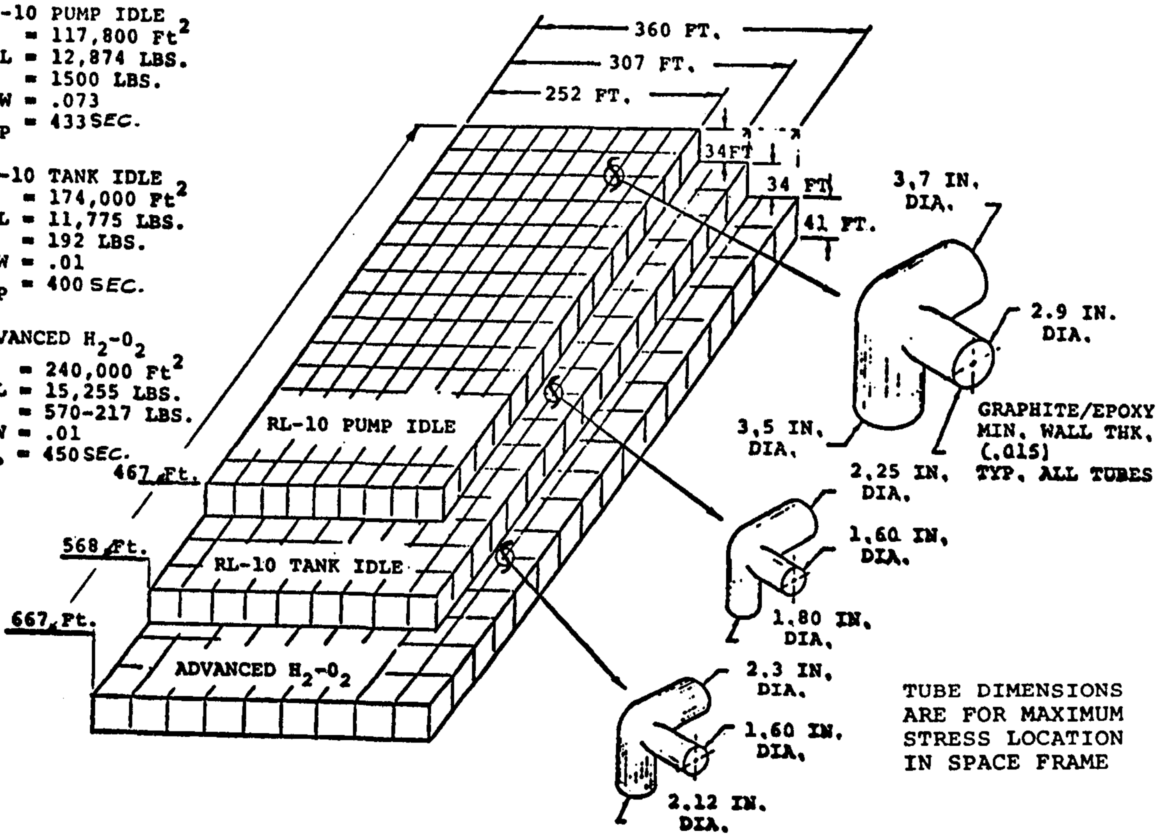
It should be emphasized that the numbers in this chart (and throughout this paper) are preliminary. System and configuration optimization procedures have not been completed.

LSS PAYLOAD CAPABILITY

RL-10 PUMP IDLE
A = 117,800 Ft^2
P/L = 12,874 LBS.
F = 1500 LBS.
T/W = .073
I_{SP} = 433 SEC.

RL-10 TANK IDLE
A = 174,000 Ft^2
P/L = 11,775 LBS.
F = 192 LBS.
T/W = .01
I_{SP} = 400 SEC.

ADVANCED H_2-O_2
A = 240,000 Ft^2
P/L = 15,255 LBS.
F = 570-217 LBS.
T/W = .01
I_{SP} = 450 SEC.



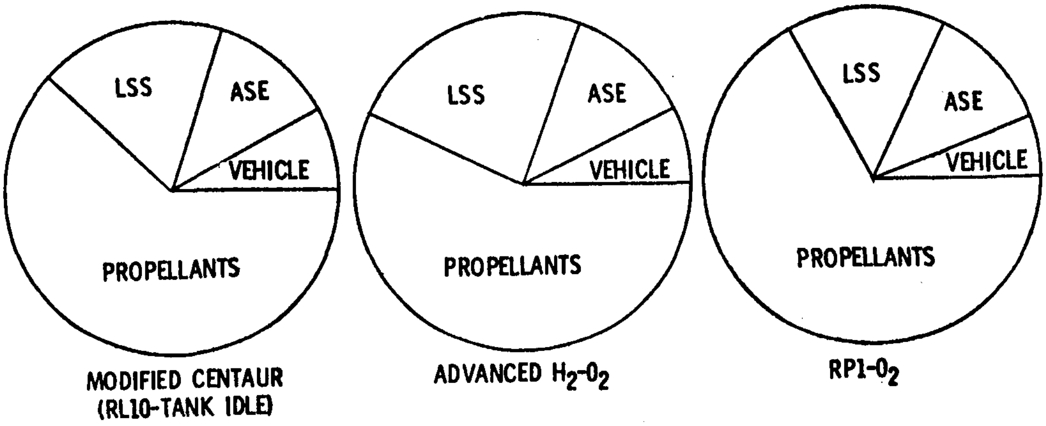
TUBE DIMENSIONS ARE FOR MAXIMUM STRESS LOCATION IN SPACE FRAME

ALL NUMBERS ARE PRELIMINARY

WEIGHT DISTRIBUTIONS OF CONCEPTUAL DESIGNS FOR LARGE SPACE STRUCTURES SYSTEMS

The weight distributions of conceptual designs for large space structures systems are shown in pie charts in the next figure. Each pie represents a Shuttle cargo bay weight of 65,000 pounds. In each case the propellant fraction of the total weight is significantly greater than fifty percent. An airborne support equipment (ASE) weight of 8000 pounds was assumed for each case. Again, the heaviest (largest deployed area) payload results from using the advanced H_2-O_2 propulsion system. Note that the vehicle weight is not minimized by using the high specific impulse advanced H_2-O_2 engine. The RP1-O_2 vehicle weight is small because the RP1 fuel is much more dense than the H_2 fuel.

WEIGHT DISTRIBUTIONS OF CONCEPTUAL DESIGNS FOR LARGE SPACE STRUCTURES SYSTEMS



ASE • AIRBORNE SUPPORT EQUIPMENT
LSS • LARGE SPACE STRUCTURE

CONCLUSIONS

- INTERACTIONS AMONG PROPULSION SYSTEM, PAYLOAD STRUCTURES AND SHUTTLE ARE IMPORTANT. FURTHER STUDY IS NEEDED.
- LOW THRUST-TO-WEIGHT RATIOS ARE DESIRABLE TO MAXIMIZE PAYLOAD WEIGHTS AND DEPLOYED AREAS.