EFFECT OF ORBITAL TRANSFER LOADS ON LARGE PLATFORMS

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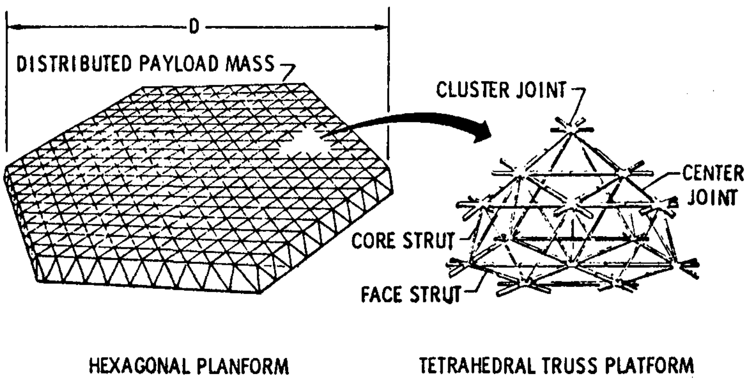
SPACECRAFT CONFIGURATION

(Figure 1)

The general outline of this presentation is to first discuss a preliminary automated structural sizing procedure suitable for conceptual design and early tradeoff studies of large truss platforms configured for Shuttle transportation to LEO. Then some orbital transfer design considerations are discussed. Finally, platforms that are sized to withstand orbital transfer loads for the LEO to GEO maneuver are compared to platforms sized only for LEO application.

The first figure depicts a flat tetrahedral truss of hexagonal planform. The maximum dimension of the platform is designated as D. There is a uniformly distributed functional surface attached to one face of the platform. This nonstructural surface is termed the payload mass, M_p. The top face of the platform can be thought of as composed of "rings". The number of rings can be identified by the number of members along an edge of the top surface. The blowup of a small portion of the truss indicates that the top and bottom surfaces are constructed of face columns or struts. The top and bottom surfaces are separated by core struts, and all struts are interconnected by cluster points which accomodate nine struts per node. The face struts contain a hinged center joint to permit packaging.

SPACECRAFT CONFIGURATION



HEXAGONAL PLANFORM TETRAHEDRAL TRUSS PLATFORM

DEPLOYABLE PACKAGING

(Figure 2)

This presentation considers only deployable trusses although information on both deployable and erectable trusses is contained in references 1 and 2. The left side of the figure identifies the six sizing variables used in the optimization process, namely; the lengths, outer diameters, and thickness of face and core struts. All face struts are identical as are all core struts.

Both inward and outward folding trusses have been examined. In most instances the outward folding truss is the least efficient, therefore the results presented here are for the inward folding truss. Note that for the inward folding truss, the face strut length can be no greater than the core strut length for tight packaging, and the core strut length can be no greater than 18 m because of the cargo bay length of the Space Shuttle.

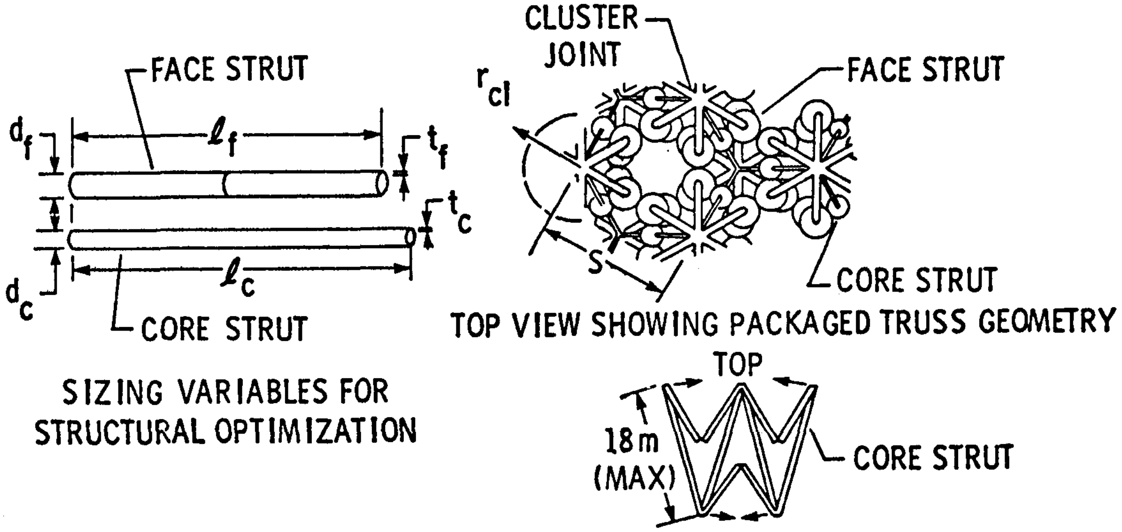
The upper right sketch depicts a planview of the platform in the tightest packaged configuration (structure only, with no surface covering material). In this view the axes of all struts are oriented perpendicular to the plane of the paper so that the struts appear as circles. The larger circles indicate face strut halves and the smaller circles indicate core struts.

REFERENCES

1. Heard, W. L., Jr.; Bush, H. G.; Walz, J. E.; and Rehder, J. J.: Structural Sizing Considerations for Large Space Platforms, AIAA Paper No. 80-0680, presented at the 21st Structures, Structural Dynamics and Materials Conference, May 12-14, 1980.

2. Bush, H. G..; Heard, W. L., Jr.; Walz, J. E.; and Rehder, J. J.: Deployable and Erectable Concepts for Large Spacecraft, SAWE Paper No. 1374, presented at the 39th Annual Conference of the Society of Allied Weight Engineers, Inc. May 12-14, 1980.

DEPLOYABLE PACKAGING



SIZING VARIABLES FOR STRUCTURAL OPTIMIZATION

TOP VIEW SHOWING PACKAGED TRUSS GEOMETRY

PACKAGE WITH INWARD FOLDING FACE STRUTS

STRUCTURAL OPTIMIZATION APPROACH

(Figure 3)

Several different math programming routines are available for optimization purposes. The one used for this study is CONMIN (ref. 3). The platform structural mass per unit area was minimized with respect to the sizing variables. Upper and lower bounds are used to constrain the sizing variables. The platform was required to have a natural frequency greater than or equal to a specified design value (i.e. to permit control). The individual struts were required to have a natural frequency which was a multiple of the platform design frequency to avoid coupling. The Euler buckling loads of the struts were required to be greater than or equal to the imposed loads. Loads due to deployment were assumed small since controlled deployment was assumed. Loads due to gravity gradient were considered but were found to be insignificant.

REFERENCE

3. Vanderplaats, Garret N.: CONMIN - A FORTRAN Program for Constrained Function Minimization. User's Manual. NASA TM X-62,282, 1973.

STRUCTURAL OPTIMIZATION APPROACH

- MINIMIZE PLATFORM STRUCTURAL MASS PER UNIT AREA,

$$\left(\frac{M}{A}\right)_{\text{PLATFORM}} = \left(\frac{M}{A}\right)_{\text{STRUTS}} + \left(\frac{M}{A}\right)_{\text{JOINTS}}$$

- WITH RESPECT TO STRUT PROPORTIONS,

THICKNESSES
DIAMETERS
LENGTHS

- SUBJECT TO DESIGN REQUIREMENTS AND CONSTRAINTS.
- OPTIMIZER -- CONMIN COMPUTER PROGRAM.

CHARACTERISTICS OF MINIMUM MASS LEO PLATFORMS UP TO 500 M

(Figure 4)

Optimization results for platforms with diameters, D, up to 500 m are shown in this figure for various constraints. The platforms were required to have a frequency of at least .1 Hz, the struts were required to have a frequency of 10 times the platform design frequency, and the mass of the platform covering was specified to be .1 kg/m^2, which is typical of a low mesh reflector surface. The strut material was graphite-epoxy. Gravity gradient loads were found to be very small. The frequency requirement of the struts sized the struture which resulted in long, small diameter, thin tubes. Minimum mass platforms are characterized by ultra low structural masses (on the order of reflector mesh).

CHARACTERISTICS OF MINIMUM MASS LEO PLATFORMS UP TO 500 M

$f_d = .1\,\mathrm{Hz}$ $\quad$ $f_s/f_d \geq 10$ $\quad$ $m_p = .1\,\mathrm{kg/m^2}$

STRUT FREQUENCY CONSTRAINT DETERMINES SIZE RESULTING IN:

- o MINIMUM ALLOWABLE THICKNESSES .5MM (.020 IN.)
- o MINIMUM ALLOWABLE DIAMETERS .0127M (.5 IN.)
- o LONG LENGTHS 7.38M (24.2 FT.)
- o LARGE SLENDERNESS RATIOS AND THUS SMALL AXIAL LOAD CARRYING CAPABILITY

EFFECT OF T/W_0 ON MASS DELIVERED

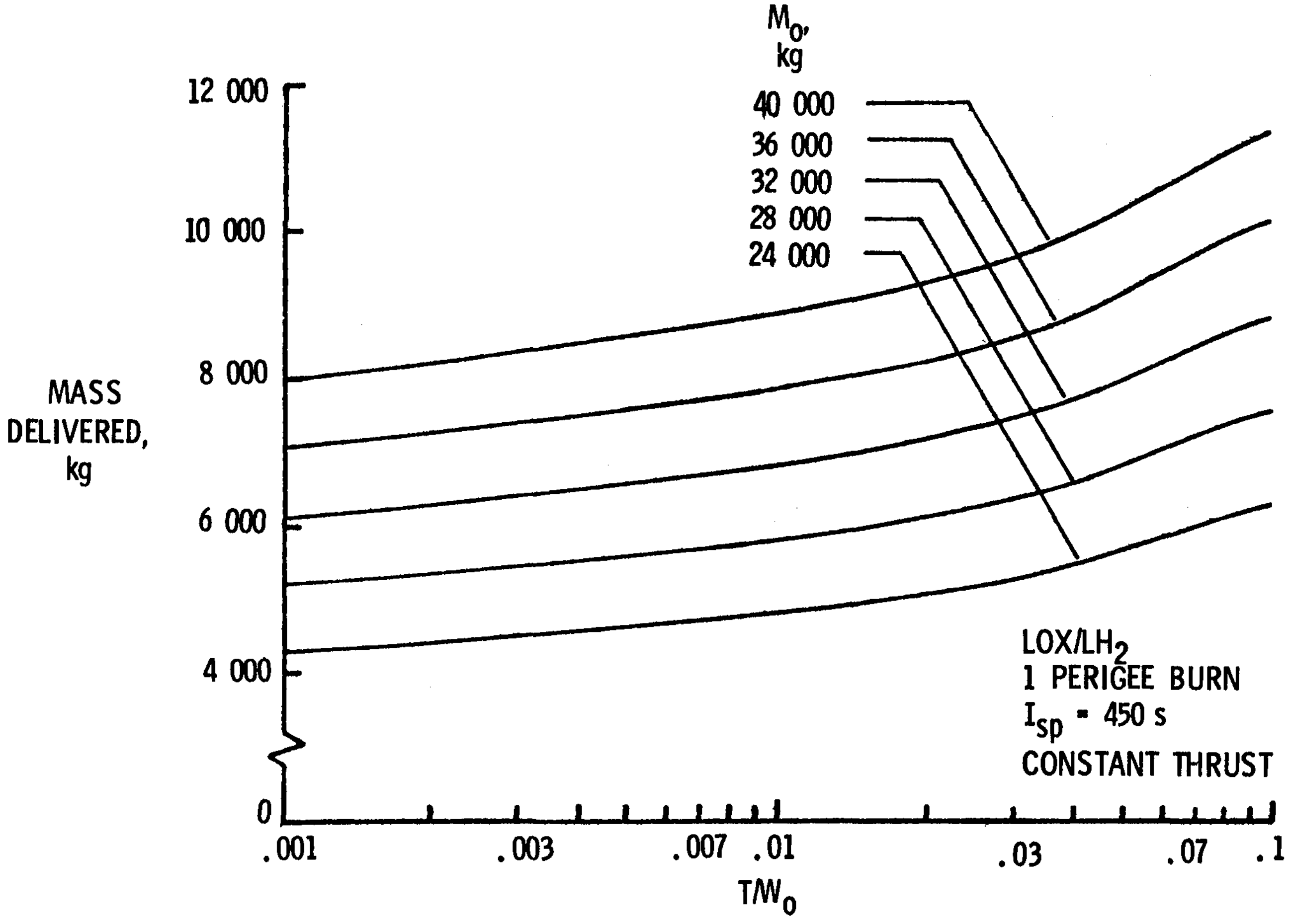
(FIGURE 5)

As a prelude to incorporation of orbital transfer loads, the amount of usable mass that is delivered from LEO to GEO as a function of initial thrust-to-weight ratio is depicted in this figure. In addition the dry mass or mass associated with empty tanks, engines, piping, thrust structure, etc. is also delivered but not shown by these curves. These curves, obtained through the use of the Aerospace Vehicle Interactive Design (AVID) system (ref. 4), are for a liquid oxygen/liquid hydrogen system with constant thrust for one perigee burn. Even though multiple perigee burns increase the amount of usuable payload delivered at the expense of longer trip times, for the initial assessment undertaken here, results for only one perigee burn were developed.

REFERENCE

4. Wilhite, A. W.; and Rehder, J. J.: AVID - A Design System for Technology Studies of Advanced Transportation Concepts. AIAA Paper No. 79-0872, presented at the Conference on Advanced Technology for Future Space System, May 1979.

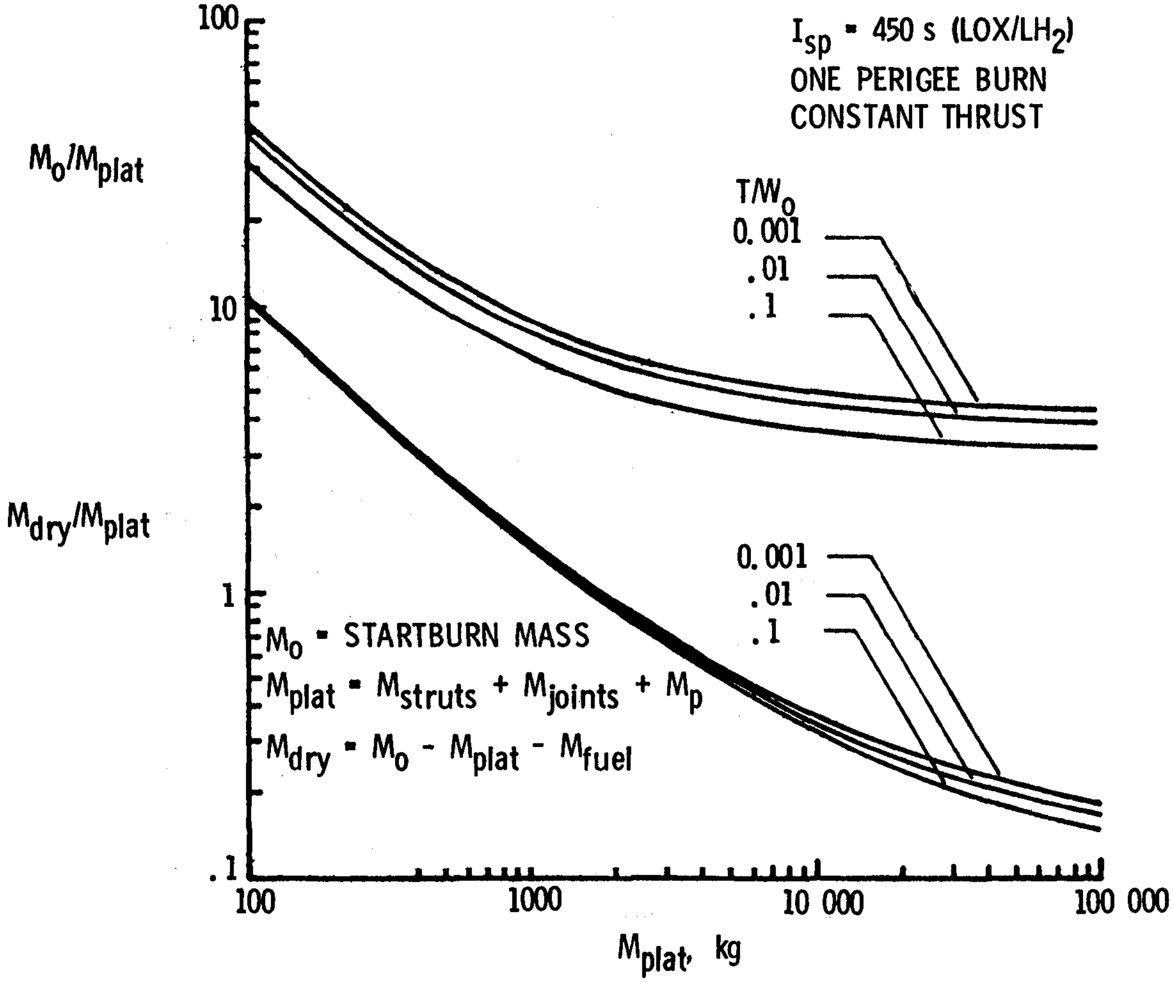
EFFECT OF T/W_0 ON MASS DELIVERED



RATIOS OF STARTBURN MASS AND DRY MASS
TO PLATFORM MASS AS A FUNCTION OF PLATFORM MASS
(Figure 6)

The information presented in the previous figure can be recast to show the ratio of M_0/M_{plat} as a function of the spacecraft or platform mass. Similarily, the ratio of M_{dry}/M_{plat} as a function of platform mass for selected values of initial thrust-to-weight ratio is shown. This information is incorporated into the sizing procedure. Observe that the mass of the platform contains the distributed mass of the covering, M_p. Also M_0, the starburn mass, is related to the weight, W_0, by g_0 the acceleration of gravity at earth's surface. The motivation for these curves is illustrated in the next figure.

RATIOS OF STARTBURN MASS AND DRY MASS TO PLATFORM MASS
AS A FUNCTION OF PLATFORM MASS



ORBITAL TRANSFER THRUST APPLICATION

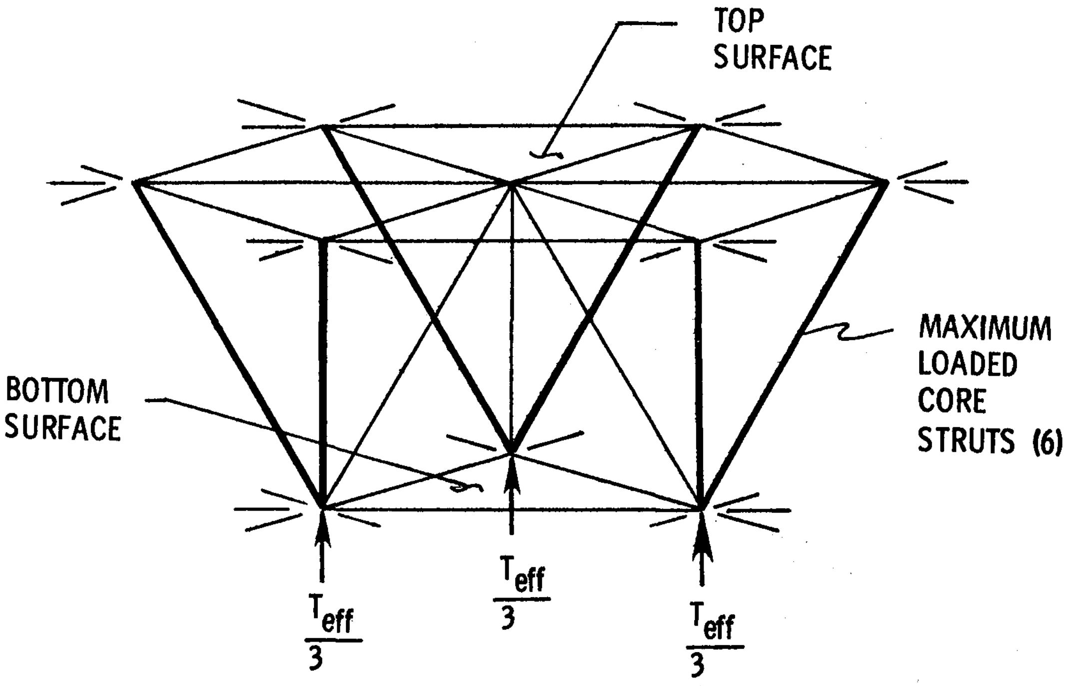
(Figure 7)

A Sketch of the central portion of the tetrahedral truss is depicted in this figure. The thrust load from the engines is introduced at the corners of a centrally located triangle normal to the plane of the back surface. Transient effects of the load were ignored for this initial assessment.

With the struts considered to be pinjointed, the maximum core strut loads occur in six of the nine core struts that connect the bottom triangle to the top surface. The three centermost core struts are essentially unloaded. The remaining six core struts carry the effective thrust load. Effective thrust here means the total thrust minus the dry mass times the final acceleration. The relationship for maximum core load can be manipulated in terms of thrust-to-weight ratio and other mass ratios shown in the previous figure.

For purposes of this sizing study, in which all core struts are identical, all core struts are sized to carry this maximum axial load. The face struts are also sized on the basis of the maximum core struts even though the maximum compressive load in a face strut is less than the maximum core strut load for D/h less than about 25 where h is the depth of the truss.

ORBITAL TRANSFER THRUST APPLICATION



$$T_{eff} = T - m_{dry}\, a_{end}$$

$$Pc_{max} = \frac{1}{6} \frac{\ell_c}{\sqrt{\ell_c^2 - \frac{1}{3}\ell_f^2}}\, T_{eff}$$

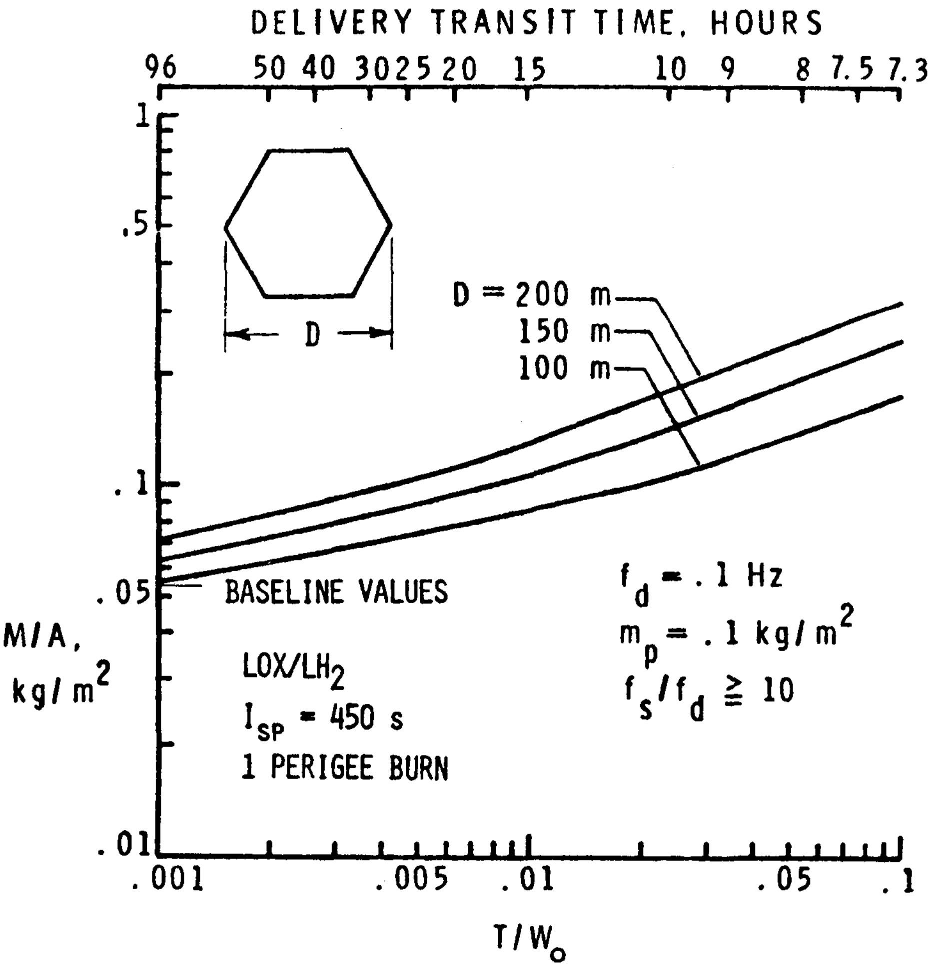
$$Pc_{max} = \frac{1}{6} \frac{\ell_c}{\sqrt{\ell_c^2 - \frac{1}{3}\ell_f^2}} \left(\frac{T}{W_0}\right) \left(\frac{M_0}{M_{plat}}\right) M_{plat}\, g_0 \left(\frac{1}{1 + M_{dry}/M_{plat}}\right)$$

MASS PER UNIT AREA AS A FUNCTION OF T/W

(Figure 8)

Mass per unit area as a function of initial thrust-to-weight ratio is depicted in this figure for three platform sizes. The propulsion system is assumed to be contained within another Shuttle such that maximum length for the struts is still 18 m. Indicated at the top of the figure is the time it takes for transporting the platform from LEO to GEO. The trusses for GEO application have the same design constraints used previously for LEO platforms. The mass per unit area for the LEO platforms, which is almost identical for the three sizes, is indicated by BASELINE VALUES on the figure.

MASS PER UNIT AREA AS A FUNCTION OF T/W

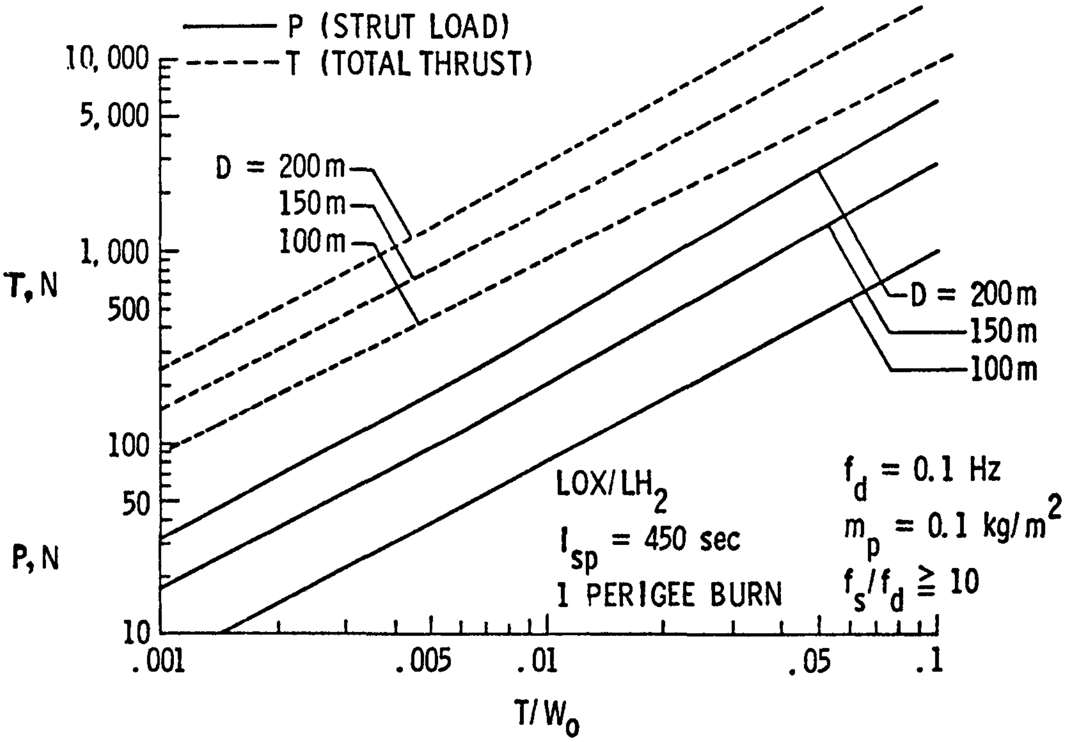


EFFECT OF ORBITAL TRANSFER ON DEPLOYABLE PLATFORM STRUT LOADS

(Figure 9)

The total thrust and maximum core strut load resulting from the chemical propulsion system and design constraints considered are depicted in this figure. The calculations were made without consideration of the availability of a given thrust level engine. The resulting range for thrust is not too different from that being proposed for low thrust chemical engines. Strut are shown to be lightly loaded except for the very highest values of T/W_0.

EFFECT OF ORBITAL TRANSFER ON DEPLOYABLE PLATFORM STRUT LOADS



COMPARISONS OF 100 M LEO AND GEO PLATFORMS

(Figure 10)

This figure compares 100 m diameter platforms sized for LEO and GEO showing the influence of orbital transfer loads. As the thrust-to-weight ratio is increased the minimum mass struts are found to become longer and larger in diameter. They are characterized by minimum gauge thicknesses and exhibit rather large slenderness ratios. In previous figures the parametric results presented did not exhibit an integer number of rings. The reults in this figure are for minimum mass designs constrained to have an integer number of rings.

COMPARISONS OF 100 M LEO AND GEO PLATFORMS

$f_d = .1$ Hz $\qquad f_s/f_d \geqq 10 \qquad m_p = .1$ kg/m^2

ORBIT	LEO	GEO	GEO	GEO
T/W_0	0.0	0.001	0.01	0.1
T/W_{FINAL}	0.0	0.0036	0.033	0.272
NUMBER OF RINGS	7	7	4	3
$\ell_f \ \ell_c$	7.143 m	7.143 m	12.500 m	16.667 m
$t_f \ t_c$	0.5 mm	0.5 mm	0.5 mm	0.5 mm
$d_f \ d_c$	0.0127 m	0.0127 m	0.0387 m	0.1070 m
f_{plat}	2.77 Hz	2.77 Hz	5.86 Hz	9.29 Hz
f_c	1.16 Hz	1.16 Hz	1.19 Hz	1.86 Hz
NUMBER OF STRUTS	1302	1302	420	234
ℓ/ρ	1591	1591	913	440

COMPARISONS OF 200 M LEO AND GEO PLATFORMS

(Figure 11)

This figure compares 200 m diameter platforms sized for LEO and GEO showing the influence of orbital transfer loads. Many of the same observations about 100 m diameter platmeter platforms hold true. The maximum length for struts is reached at lower values of thrust-to-weight than for 100 m platforms. The frequencies for these larger structures are lower than 100 m platforms and lower values of slenderness ratios are obtained but are still large compared to those of earth based structures.

COMPARISONS OF 200 M LEO AND GEO PLATFORMS

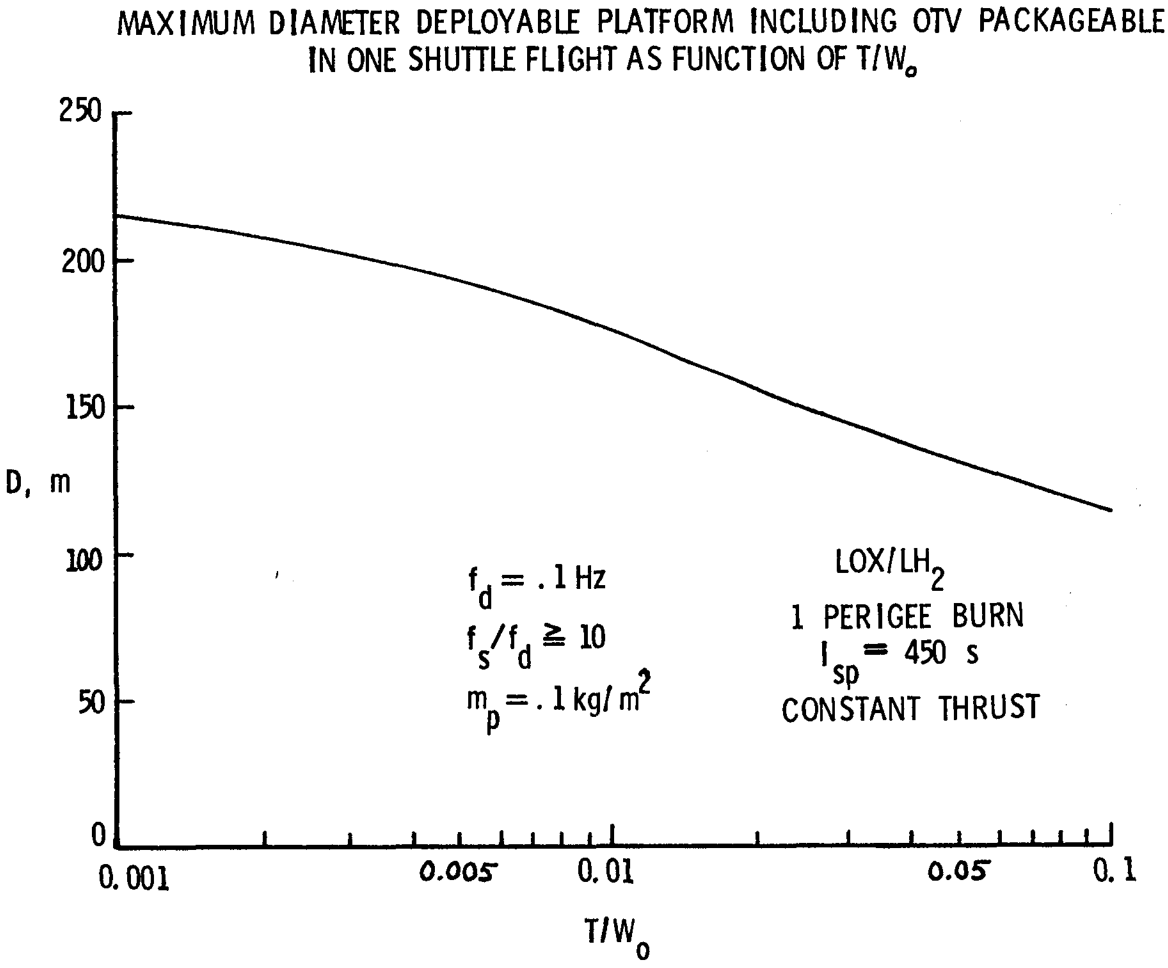
$f_d = .1$ Hz $\qquad f_s / f_d = 10 \qquad m_p = .1$ kg/ m^2

ORBIT	LEO	GEO	GEO	GEO
T/W_0	0.0	0.001	0.01	0.1
T/W_{FINAL}	0.0	0.0036	0.033	0.272
NUMBER OF RINGS	13	9	6	6
ℓ_f, ℓ_c	7.692 m	11.111 m	16.667 m	16.667 m
t_f, t_c	0.5 mm	0.5 mm	0.5 mm	0.5 mm
d_f, d_c	0.0127 m	0.0263 m 0.0274 m	0.0792 m	0.1953 m
f_{plat}	0.75 Hz	1.22 Hz	2.19 Hz	2.53 Hz
f_c	1.00 Hz	1.02 Hz	1.38 Hz	3.28 Hz
NUMBER OF STRUTS	4524	2160	954	954
ℓ/ρ	1713	1195	595	241

MAXIMUM DIAMETER DEPLOYABLE PLATFORM INCLUDING OTV PACKAGEABLE IN ONE SHUTTLE FLIGHT AS FUNCTION OF T/W_0

(Figure 12)

Up to this point, the sizing procedure generated minimum mass platforms. This figure shows platform size results when the surface area is maximized for the same design constraints used previously. In addition, the mass and volume of the OTV (Orbital Transfer Vehicle) are assumed to package with the structure in one shuttle flight. Since the OTV takes up more than half of the shuttle bay length, only the remaining length is available for packaging the structure. This curve is an upper bound on size because although the distributed non structural or payload mass is considered, the volume associated with its packaging is not.



CONCLUSIONS

(Figure 13)

For platforms supporting low mass distributed payloads (reflector mesh, etc.), platform and strut frequency requirements (i.e. stiffness) are strong design drivers for LEO applications. The struts are found to be extremely slender, thin-walled, and small diameter. If full advantage is to be taken of these minimum mass designs, a manufacturing capability must be developed for long straight struts. For platforms that are to be transferred from LEO to GEO in a deployed state, the orbital transfer loads become design drivers. However, even for an initial thrust-to-weight ratio equal 0.1, a platform on the order of 100 m in diameter appears packageable with its OTV in one shuttle flight, and larger platforms appear possible at lower thrust-to-weight ratios.

CONCLUSIONS

- PLATFORM AND STRUT FREQUENCY REQUIREMENTS ARE STRONG STRUCTURAL DESIGN DRIVERS FOR LEO PLATFORMS
- MANUFACTURING CAPABILITY MUST BE DEVELOPED TO MEET HIGH STRUT SLENDERNESS RATIOS
- ORBITAL TRANSFER LOADS BECOME PREDOMINANT DESIGN DRIVERS FOR GEO PLATFORMS