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21

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MOL PROGRAM STRUCTURAL CRITERIA FOR THE LABORATORY VEHICLE SEGMENT

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El Segundo, California

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DEPUTY DIRECTOR
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The information in a Technical Operating Report is developed for a particular program and is therefore not necessarily of broader technical applicability.

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CONTENTS

1.0 INTRODUCTION

1.1 SCOPE

This document presents the basic requirements and information governing the structural design for the Laboratory Vehicle (LV) system segment of the Manned Orbiting Laboratory (MOL) System.

Included herein are the following:

a. Basic facts and references pertinent to the structural design.
b. Basic objectives for the philosophy of structural design.
c. Conditions and environments for which the vehicle must be investigated and designed.
d. Requirements for establishing loads and other environmental factors for the design conditions.
e. References.

1.2 AUTHORITY

This document has been converted to SAFSL Exhibit 10004 which governs the design of all vehicle structural components. Any deviation from the requirements of SAFSL Exhibit 10004 shall be noted, along with proper justification.

1.3 INTENT

The intent of these criteria is to provide a set of design conditions, requirements, and objectives ~~which,~~ when implemented, will ensure that the structural components achieve acceptable and compatible structural integrity.

1.4 DEFINITIONS

The following list provides definitions for words and phrases used in this report.

Limit Load	The maximum anticipated load, or combination of loads, which a structure may be expected to experience during the performance of specified missions in specified environments.
Ultimate Load	Obtained by multiplying the limit load by the ultimate factor of safety.
Factor of Safety	An arbitrary value to account for uncertainties and variations from item to item in material properties, fabrication quality and details, and internal and external load distributions.
Applied Temperatures	Maximum calculated temperatures to which the structure will be subjected during the performance of specified missions in specified environments.
Critical Condition	A loading or temperature condition, or combination thereof, which dictates the design of a portion of the structure.
Failure	A structure is considered to have failed when it can no longer perform its intended function. Failure of a structure may result in loss of the vehicle, or any part thereof, and may present a hazard to operating personnel.
Excessive Deformations	Deformations, elastic or inelastic, resulting from application of loads and temperatures, are excessive when any portion of the LV structure can no longer perform its intended function, reducing the probability of successful completion of the mission below the prescribed limits.
Pressure Vessels	Containers that must sustain an internal pressure (including inhabited areas, propellant tanks, solid motor cases, nozzles, thrust chambers, liquid or gas storage bottles, plumbing, tubing, piping, etc., but excluding adapters, interstages, skirts, or fins).

Nominal Pressure	The rated operating pressure of the system.
Maximum Expected Operating Pressure (MEOP)	The maximum anticipated operating pressure including the effects of temperature, transient peaks, and variations in pressure and vehicle acceleration.
Limit Pressure	Same as MEOP, above.
Ultimate Pressure	The limit pressure multiplied by the appropriate safety factor.
Proof Pressure	That pressure which is applied to a pressure vessel in a test at room temperature as evidence of satisfactory workmanship and material quality. Proof pressure is derived by multiplying limit pressure by the proof pressure factor.
Proof Pressure Factor	The proof pressure factor shall be defined for each class of pressure vessel utilized in the system. The proof pressure factor shall be selected to demonstrate a predetermined minimum margin of safety with respect to the MEOP, and shall include the effects on material properties resulting from differences between the test temperature and the design temperature. The nominal stress at proof pressure shall be less than the minimum guaranteed yield strength of the material.
Burst Pressure	Burst pressure is the pressure which an article must sustain in a room-temperature test without rupture. Burst pressure is the ultimate pressure adjusted for the effects on material properties resulting from differences between the test temperature and the design temperature.
Erection Phase	That time period from erection of the launch vehicle to removal of the gantry or other external support.
Prelaunch Phase	That time period from removal of gantry or other support until vehicle liftoff.

Launch Phase	That time period from vehicle liftoff until the launch transients damp out.
Ascent Phase	That time period from launch transients damp out to ascent vehicle burnout.
Orbit Phase	That time period from ascent vehicle burnout to deorbit.
Destructive Flutter	Flutter of a catastrophic nature (rapid breakup of structure) and limited-amplitude flutter which will cause functional failure of equipment or structure.

2.0 DESIGN CRITERIA

2.1 GENERAL DESIGN PHILOSOPHY

The structure shall possess sufficient strength, rigidity, and other characteristics necessary to survive the critical loading conditions and environments that exist within the envelope of mission requirements. It shall survive those conditions and environments in a manner that does not reduce the probability of successful completion of the mission below the prescribed limit. Consistent with the structural design principles and assumptions listed herein, and in MIL-M-8555A, the structure shall be designed to achieve minimum weight wherever practicable. Proper consideration shall be given to the effect on system cost and on the development schedule.

The structure shall be designed to the critical flight conditions wherever possible. A design objective shall be that the nonflight conditions and environments shall not increase the flight weight over that required for the flight conditions.

2.1.1 Design Conditions and Environments

The environmental phenomena corresponding to each design condition shall include all factors that can influence the structural design (including heating, vibration, shock and acoustics, as well as quasi-static and dynamic loads). Consideration shall be given to the deteriorating effect of prolonged exposure to the space environment. Where possible, all such phenomena shall be determined statistically.

2.1.1.1 External and Internal Load Distribution

External loads shall be determined by conservative analyses of the design environment. The aerodynamic loads may be determined from appropriate wind tunnel tests or calculated by conservative methods considered to be sound engineering practice. The effects of aeroelasticity on the distribution and intensity of loads shall be considered.

The internal structural load distribution shall be determined by rational analyses. Effects of deformations, nonlinearities, and temperature on internal load distribution shall be included in analyzing the load distribution.

2.1.1.2 Combined Loads and Internal Pressure

When internal pressure effects in combined load conditions are stabilizing or otherwise beneficial to structural load capability, the nominal internal operating pressure for that condition shall be used instead of the ultimate design internal pressure in the loads analysis.

2.1.1.3 Malfunctions

The LV structure shall not be designed to withstand loads produced by any subsystem malfunction that would otherwise result in failure to accomplish the mission. Malfunctions shall not result in structural failures which jeopardize the probability of successful crew abort.

2.1.1.4 Misalignment and Dimensional Tolerances

The effects of allowable structural misalignments, control misalignments, and other permissible and expected dimensional tolerances shall be considered in the analysis of all limit loads, loads distributions, and structural adequacy.

2.1.1.5 Dynamic Loads

Dynamic loads shall be determined for all quasi-static and transient phenomena expected in each design environment. The calculation of all dynamic loads shall consider the effects of vehicle structural flexibilities, and damping and coupling of structural dynamics with the control system and the external environment.

2.1.1.6 Load and Thermal Fatigue

The effects of repeated loads and elevated and/or cryogenic temperature will be considered in the structural design. The design structural adequacy of the vehicle in flight shall not be impaired by fatigue damage resulting from exposure to nonflight and launch environments.

2.1.1.7 Vibrational and Acoustical Loadings

The effects of the vibrational and acoustical environments shall be accounted for in design wherever possible by rational analysis of the response of the dynamic system to the environment.

2.1.1.8 Creep Deformation

The effects of permanent creep deformation shall be considered by rational methods of analyses. Where not otherwise critical (i.e. creep, buckling, etc.), a permanent deformation of one percent shall be the maximum permissible value.

2.1.1.9 Thermal Stresses

The effects of thermal stresses shall be combined with the appropriate load stresses when calculating required strength. Thermal stresses shall be based on the applied temperatures, heating rates, etc., and shall be considered limit values.

2.1.2 Material Properties and Allowables

Material strengths and other mechanical and physical properties shall be selected from authorized sources of reference, such as Ref. 1, and from contractor test values, when appropriate. Strength allowables and other mechanical properties used shall be appropriate to the loading conditions, design environments, and stress states for each structural member.

Allowable material strengths used in the design shall reflect the effects of load, temperature, and time associated with the design environment, either individually or in combination, as applicable. Allowable yield and ultimate properties are as follows:

a. For single-load path structures, the minimum guaranteed values shall be used.
b. For multiple-load path structures, the 90 percent probability values shall be used.

These values shall be consistent with overall reliability requirements.

2.1.3 Strength Requirements

2.1.3.1 At Limit Load

The structure shall be designed to have sufficient strength to withstand the limit loads resulting from aerodynamic pressures, inertia accelerations, applied temperature, etc., which combine at any one time to result in the highest induced stresses and minimum allowable without experiencing plastic deformation or excessive elastic deformations.

2.1.3.2 At Ultimate Load

The structure shall sustain the ultimate loads resulting from aerodynamic pressures, inertia, acceleration, applied temperatures, etc., which combine at any one time to result in the highest induced stresses and minimum allowables.

2.1.3.3 Margin of Safety

Margin of safety is defined as $MS = 1/R - 1$, where R is the ratio of applied load (or stress, as applicable) to the allowable load (or stress). In determining the factor R, the effects of combined loads or stresses (interaction) shall be included.

For minimum weight, the structure shall be designed to the smallest permissible margins of safety, which shall be zero, except in certain specific instances where specified finite values may be required.

2.1.4 Stiffness Requirements

2.1.4.1 Under Limit Loads

The structure shall not experience permanent deformation at limit load and in the appropriate design environment.

2.1.4.2 Under Ultimate Loads

Structural deformations shall not precipitate structural failure during any design conditions and/or environment at loads equal to or less than ultimate loads.

2.1.4.3 Aeroelastic Requirements

Destructive flutter or related dynamic instability or divergence phenomena shall not occur on the vehicle, or its components, at any condition along the design trajectories. To ensure safety, it shall be shown by analytical and/or experimental data that, at any altitude along the trajectory, an increase of 30 percent in the dynamic pressure will not result in destructive flutter or divergence.

2.1.4.4 Internal Support Structure

The basic chassis of the components (50 lb or less) and the immediate support structures (not including trusses) shall have fundamental resonant frequencies greater than 55 cps. Vibration isolation techniques and associated analyses must be approved by the MOL SPO, unless it is proven by analysis or test that the item will not fail.

2.1.5 Thermal Requirements

The effects of temperature shall be considered in design of the vehicle. Thermal analysis shall be based on rational transient analysis of heat fluxes from aerodynamic heating, engine exhaust gas radiations, engine system and electronic equipment heat sources, including consideration of the heat sink effect of the mass of structure, fuel, and equipment.

Aerodynamic heating shall be based on the design trajectories (paragraph 2.2). Aerodynamic heating rates shall be calculated by use of techniques considered to be sound engineering practice.

Thermal effects on the structure (including heating rates, temperature, thermal stresses, and deformations), and mechanical and physical property changes will be based on critical design heating environments.

2.1.6 Safety Factors

Safety factors for the vehicle shall be as shown in Table 1.

Table 1. Safety Factors

	Limit	Proof	Ultimate
Flight Loads			
Air Loads	1.00	---	1.40
Thrust Loads	1.00	---	1.25
Abort Loads	1.00	---	1.10
Transient Dynamic Loads	1.00	---	1.40
Nonflight Loads (other than pressure)			
Dangerous to personnel	1.00	---	1.50
Remote from personnel	1.00	---	1.25
Pressure Loads			
Propellant tanks	1.00	*	2.00
Cryogenic tanks	1.00	*	2.00
Rocket motor cases	1.00	*	2.00
Pneumatic Vessels (including accumulators and pressurization bottles) (see Ref. 3)	1.00	*	2.00
Manned Cabins	1.00	*	2.00
Hydraulic Vessels (including accumulators, pressurization bottles, radiators, and cooling systems) (see Ref. 4)	1.00	2.00	4.00
Hydraulic Vessels (normally under oil pressure only) (see Ref. 4)	1.00	1.50	2.00
Hydraulic and Pneumatic (lines, fittings, and hoses) (see Refs. 3 and 4)	1.00	2.00	4.00
Propellant (supply and vent components)	1.00	*	2.00

When it can be shown by rational analysis that higher or lower factors of safety than those listed above are consistent with attainment of specified probabilities of mission success/crew safety, such factors may be substituted.

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*See paragraph 1.4, Definitions

2.2 DESIGN PHASES

2.2.1 Ground Phase

Structural design considerations shall include all environments to which structure and its component parts are exposed during manufacturing, storage, handling, transportation, and erection. Except for local attachments and structure (such as ground-bearing structure), the ground loads shall not govern design of the structure, if practicable.

2.2.2 Prelaunch and Erection Phases

The vehicle shall be capable of sustaining all prelaunch and erection design load conditions as specified in Ref. 5.

2.2.3 Launch Phase

The vehicle shall be capable of sustaining all design load conditions as may be experienced during launch operations, as specified in Ref. 5. Consideration shall be given to the loading and environment induced by abort during this phase.

2.2.4 Ascent Phase

The vehicle structure shall be designed for the entire powered flight environment, as specified in Ref. 5. Consideration shall be given to the loading and environment induced by abort during this phase.

2.2.5 Orbit Phase

The vehicle shall be designed for all geophysical environments and loading conditions associated with orbital flight.

The design of the vehicle and its parts shall be based on, but not limited to, consideration of the following conditions:

2.2.5.1 Maneuvering Loads

Loads resulting from maneuvers for changing orbits, station keeping, attitude control, etc., as well as any other maneuver necessary for the completion of the mission shall be determined and shall include the interaction of the propulsion system and the guidance and/or control system with the flexible vehicle.

2.2.5.2 Meteoroid Environment

The MOL vehicle will encounter a flux of meteoroids as it orbits the Earth. The magnitude and characteristics of this flux shall be taken as specified in paragraph 3.2.5 c. of Ref. 5. The vehicle structure, pressurized volumes, space radiators (tubes and also fins, if used as part of the meteoroid protection structure), solar panels, etc., shall be designed to achieve the required probability of no destructive penetrations by meteoroids for the duration of the mission. A destructive penetration is one which impairs the function of the punctured element. The following criteria shall be utilized:

a. Meteoroid Penetration - The minimum thickness of structure necessary to resist penetration by a meteoroid mass less than a given mass m, shall be determined from the formulas given below.

(1) Single-Plate Wall

The thickness-mass relationship for a single-plate wall shall be taken as

$$t = 148\ K_1 \left(\frac{m}{E_t\ \rho_t}\right)^{1/3}$$

where

t is the thickness of the wall, in.

m is the meteoroid mass, gm

E_t is Young's modulus of the wall material, psi

ρ_t is the weight density of the wall material, lb/cu in.

K_1 is the single-plate wall effectiveness factor

To prevent perforation only, K_1 shall be taken as 1.5.

To prevent spalling of the inner face as well as perforation (i.e., space radiator tube application) K_1 shall be taken as 2.25.

(2) Double-Plate Wall

The thickness-mass relationship for a double-plate wall shall be taken as

$$t = 222\ K_2 \left(\frac{m}{E_t \cdot \rho_t} \right)^{1/3}$$

where

t is the total thickness required to prevent perforation, in.

K_2 is the double-plate wall effectiveness factor

[m, E_t, and ρ_t are defined above]

The effectiveness factor, K_2, depends on wall spacing and on whether an energy-absorbing filler is used. The values of K_2 given in Table 2 shall be used as appropriate. The values of K_2 for use with an energy absorber apply to flexible, open cell polyurethane foam of density 1.5 to 2.0 lb/cu ft. Other materials may be used, provided an equivalent effectiveness can be demonstrated.

To achieve optimum shield effectiveness and the values of K_2 listed in Table 2, the thickness of the outer plate or shield must be from 15 to 25 percent of the total thickness required.

(3) The penetration equations given in paragraphs 2.2.5.2 a. (1) and (2), above, are primarily for aluminum alloy but are considered adequate for most conventional structural materials.

2.2.5.3 Radiation Environment

The effect of both natural and artificial radiation environments shall be considered in designing the structure, radiators, solar panels, etc. These effects shall include not only the deterioration and induced radiation effects on the materials, but also the shielding that may be required for human occupants and sensitive equipment. The radiation environment is specified in Ref. 5.

2.2.5.4 Other Environments

Other environments, both natural and induced, to be used in the structural design of the vehicle are given in Ref. 5. All items and components shall be designed for the most severe environmental conditions with consideration of both operational and nonoperational states.

Table 2. Effectiveness Factor Double-Plate Wall Construction, K_2

CASE I

Two plates spaced h in. apart.

No filler between plates.

h	K_2
1.0	0.50
1.5	0.35
2.0	0.27

CASE II

Two plates spaced h in. apart.

Low-density foam, energy-absorbing medium between plates.

h	K_2
1.0	0.33
1.5	0.25
2.0	0.20

CASE III

Two plates spaced h in. apart.

Honeycomb with axis of cells normal to plates. No filler in cells.

$h < 1.0 \quad K_2 = 1.0$

$h > 2.0 \quad K_2 = 0.67$

Use a straight line interpolation of K_2 between $h = 1$ and $h = 2$.

3.0 REFERENCES

1. MIL-HDBK-5 — Strength of Metal Aircraft Elements dtd November 1964

2. MIL-M-8555A — Missiles, Guided: Design and Construction, General Specification for dtd 6 October 1960

3. MIL-P-5518C — Pneumatic Systems: Design, Installation and Tests in Aircraft dtd 9 July 1962

4. MIL-H-25475A — Hydraulic Systems: Design, Installation, and Test of Missile, General Specification for dtd 19 January 1961

5. TOR-1001(2107-30)-7 (SAFSL Exhibit 10003) — MOL Program Environmental Design and Test Criteria for the MOL System Laboratory Module, Mission Module, and AGE dtd December 1966