STRUCTURAL CRITERIA FOR LABORATORY VEHICLE FOR THE MOL PROGRAM

SAFSL EXHIBIT 30044

6 JUNE 1968

REVIEW OF

SAFSL EXHIBIT 30044

STRUCTURAL CRITERIA FOR LABORATORY

VEHICLE FOR THE MOL PROGRAM

May 22, 1968

The undersigned has reviewed the document and understands the contents to the extent necessary to scope subsequent proposals.

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4-25-68 As noted below:
Eastman Kodak
A. S. Bennett

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B. P. Crase

NOTE: Signature acknowledges agreement with this document, but such agreement does not extend to the documents referenced herein which are not yet agreed upon.

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ACTION ITEMS

DAC, GE, EK to provide for all pressurized systems the following: item, location, internal volume, operating pressure, proof and ultimate design factors of safety and associated justification, which are not in compliance with WRT range documentation. (AFWTRM 127-1 and 1 STRADM 127-200) due 23 July 1968.

SAFSL EXHIBIT 30044

MANNED ORBITING LABORATORY (MOL)

STRUCTURAL CRITERIA FOR THE LABORATORY VEHICLE

I. INTRODUCTION

(M) A. Scope

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

Included herein are the following:

1. Basic facts and references pertinent to the structural design.

2. Basic objectives for the philosophy of structural design.

3. Conditions and environments for which the vehicle must be investigated and designed.

4. Requirements for establishing loads and other environmental factors for the design conditions.

5. Definition of terms.

(R) B. Authority

This document shall govern the design of all vehicle structural components. Any deviation from these requirements shall be noted by formal request to the SPO with proper justification included.

(R) C. 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.

All deliverable data and/or documentation specified in this exhibit shall be in accordance with the respective contractor's CDRL (DD 1423 or equivalent) as detailed by Forms 9.

II. DEFINITIONS, NOMENCLATURE, AND REFERENCES

(M) A. Definitions

1. 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.

2. Ultimate Load--Obtained by multiplying the limit load by the ultimate factor of safety.

3. 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.

4. Applied Temperatures--Maximum calculated temperatures to which the structure will be subjected during the performance of specified missions in specified environments.

5. Critical Condition--A loading or temperature condition, or combination thereof, which dictates the design of a portion of the structure.

6. 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.

7. Excessive Deformations--Deformations, elastic or inelastic, resulting from application of loads and temperatures are excessive when any portion of the vehicle structure can no longer perform its intended function.

8. Pressure Vessels and Components--Containers that must sustain an internal pressure; e.g., inhabited areas, propellant tanks, solid motor cases, nozzles, thrust chambers, liquid or gas storage bottles, plumbing, tubing, piping, etc., but not adapters, interstages, skirts, or fins, even though these are acted on by internal pressure.

9. Nominal Pressure--The rated operating pressure of the system.

10. Maximum Expected Operating Pressure (MEOP)--The maximum anticipated operating pressure including the effects of temperature, transient peaks, and variations in pressure and vehicle acceleration.

11. Limit Pressure--Same as MEOP above.

12. Ultimate Pressure--The limit pressure multiplied by the appropriate safety factor.

13. Proof Pressure--That pressure which is applied to a pressure vessel for the purpose of an acceptance test. The proof pressure is derived by multiplying the limit pressure (MEOP) by the proof pressure factor of safety. (An acceptance proof pressure test is a test conducted under the appropriate environmental condition*, including temperature, for each class of pressure vessels.)

14. 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 in 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.

15. Burst Pressure--Burst pressure is the pressure which an article must sustain without rupture. Burst pressure is the ultimate pressure adjusted for the effects on material properties resulting from differences in the test temperature and the design temperature. (A burst test is a test conducted under the appropriate environmental conditions*, including temperature, for each class of pressure vessels.)

16. Erection Phase--That time period from erection of the launch vehicle to removal of the gantry or other external support.

17. Prelaunch Phase--That time period from removal of gantry or other support until vehicle liftoff.

18. Launch Phase--That time period from vehicle liftoff until the launch transients damp out.

19. Ascent Phase--The ascent phase covers the time period from launch transients dampout to ascent vehicle burnout.

20. Orbit Phase--That time period from ascent vehicle burnout to deorbit.

21. Descructive flutter is considered to be flutter of a catastrophic nature (rapid breakup of structure) and limit-amplitude flutter which will cause functional failure of equipment or structure.

22. Thrust Termination Condition--This condition is composed of axial loads due to oscillating longitudinal thrust forces caused by "blowing" the Stage "0" forward thrust ports in combination with lateral loads (shear and bending moment) from time compatible air loads conditions. This condition is caused by an abort event and can occur at any time during Stage "0" flight. The ultimate factor of safety to be used for this condition is 1. 10.

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* Appropriate environmental condition, i.e., an especially suiteble substitute conditon or a direct simulation of the design condition.

B. Nomenclature

(M)

g	=	32 feet per second squared
fps	=	feet per second
mph	=	miles per hour
psf	=	pounds per square foot
d	=	diameter of meteoroid, inches
p_p	=	density of meteoroid, gms/cc
p_t	=	weight density of the wall material, lb/in.^{3}
V	=	meteoroid velocity, fps
C	=	Velocity of an elastic wave along the axis of a slender prismatic bar of the target materials, fps
gms	=	grams
cc	=	cubic centimeter
MeV	=	million electron volts
STER	=	steradian, unit of solid angular measure
kmps	=	kilometers per second

(R) C. Applicable Documents

The following documents, of the exact issue indicated, are applicable to the extent specified. Documents called out are applicable as specified herein.

MIL-HDBK-5	Strength of Metal Aircraft Elements, Nov 1964
MIL-HDBK-17	Plastics for Flight Vehicles
SAFSL 30033	Environmental Design Criteria for MOL System Lab Module and Mission Module and Associated AGE.
SAFSL 10011	Crew Systems-Design Compatibility Criteria for the MOL Program, 1 November 1967, Preliminary
SAFSL 30012	Design Loads Criteria for the MOL Orbiting Vehicle

MIL-M-8555A	Missiles, Guided: Design and Construction General Specification for, 6 October 1960
SS-MOL-1B	System Performance and Design Requirements General Specification

Where a conflict occurs between the applicable documents and SAFSL Exhibit 30044, the latter shall govern.

III. DESIGN CRITERIA

(R) A. General

The structure shall possess sufficient strength, rigidity, and other necessary characteristics required 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 affect on system cost and development schedule.

The structure shall be designed by the critical flight conditions wherever possible. It shall be an objective that the nonflight conditions and environments shall not increase the flight weight over that required for the flight conditions.

1. Design Conditions and Environments

(R) The environmental phenomena corresponding to each design condition shall include all factors that can influence the structural design and typically include heating, vibration, shock and acoustics, in addition to 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.

a. External and Internal Load Distribution

(R,T) 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.

(R,T) 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.

b. Combined Loads and Internal Pressure

(RT) 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.

(RT) c. Malfunctions

The vehicle 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.

(RT) d. 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.

(R,T) e. 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. A final set of dynamic loads shall be determined utilizing experimental values of structural flexibilities and dynamic charcateristics as obtained from appropriate tests and assembly modal surveys.

(R,T) f. Load and Thermal Fatigue

The effects of repeated loads and elevated and/or cryogenic temperature will 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.

(R,T) g. Vibrational and Acoustical Loadings

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

(R,T) h. Creep Deformation

The effects of permanent creep deformation shall be considered by rational methods of analyses. Where not otherwise critical, e.g., alignment, a permanent deformation of 1 percent shall be considered as the maximum permissible value.

(R,T) i. Thermal Stresses

Thermal stresses shall be combined with the appropriate load stresses when calculating required strength. Thermal stresses shall be based on the applied temperature, and shall be considered limit values.

2. Material Properties and Allowables

(R) a. Material strengths and other mechancial and physical properties shall be selected from sources of reference, such as MIL-HDBK-5 and MIL-HDBK-17, and contractor allowables 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.

b. Values

(R) 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:

1) For single load path structures, the minimum guaranteed values are to be used.

2) For multiple load path structures, the 90 percent probability values are to be used.

These values are to be consistent with overall reliability requirements.

3. Strength Requirements

a. At Limit Load

(R) 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.

b. At Ultimate Load

(R) The structure shall sustain the ultimate loads (plastic deformation permissible) 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.

c. Margin of Safety

(R,T) 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 structural design shall strive for the smallest permissible margins of safety, which shall be zero, except in certain specific instances where specified finite values may be required.

4. Stiffness Requirements

a. Under Limit Loads

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

b. Under Ultimate Loads

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

c. Aeroelastic Requirements

(R,T) 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 or experimental data, or both, that at any altitude along the trajectory, an increase of 30 percent in the dynamic pressure will not result in destructive flutter or divergence.

d. Internal Support Structure

(R,T) The basic chassis of the components (Ref. Para 3.10 SAFSL Exhibit 30012) and the immediate support structures shall have fundamental resonant frequencies greater than 30 cps. Vibration isolator techniques and/or associated analyses which evaluate the design adequacy must be provided for SPO approval.

5. Thermal Requirements

(R,T) 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 (Para. III-B). 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.

(R)

6. Factors of Safety

	Limit	Ultimate
a. Flight Loads		
Air Loads, Dynamic Loads, Pressure Loads (Venting, Buffeting, etc.)		
KA Mode*	1.00	1.40
KB Mode*	1.00	1.25
Thrust Loads	1.00	1.25
Thrust Termination Loads (other than normal staging conditions)	N/A	1.10
b. Nonflight Loads (Other than pressure)		
Dangerous to personnel	1.00	1.50
Non-dangerous to personnel	1.00	1.25

* Reference SS-MOL-1B

c. Pressure Loads	Limit	*Minimum Proof	Ultimate
Propellant Storage Tanks	1.00	1.50	2.00
Cryogenic Storage Tanks	1.00	1.50	2.00
Rocket Motor Cases	1.00	1.50	2.00
Thrusters			
Pressurized Cabins (On-Orbit)	1.00	1.33	2.00
Pneumatic Systems Components			
a. Heat exchangers, accumulators, fans, blowers, valves, filters, regulators, pressure switches, pressurant tanks, quick disconnects.	1.00	1.50	2.00
b. Lines (tubing), fittings, hoses	1.00	2.00	4.00
Hydraulic Systems Components			
a. Heat exchangers, (including cold plates & cold panels), accumulators, pumps, valves, filters, regulators, pressure switches, pressurant tanks, quick disconnects.	1.00	1.50	2.00

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	Limit	*Minimum Proof	Ultimate
b. Lines (tubing, including radiator tubes), fittings, hoses	1.00	2.00	4.00
Propulsion System Components	1.00	2.00	4.00
Lines (tubing), hoses (flexible), valves, filters, regulators, switches, fittings (connectors)			
Reactants Supply System Components	1.00	2.00	4.00
Lines (tubing), valves, fittings (connectors)			
Fuel Cell System Components	1.00	1.50	2.00
Valves, regulators, heat exchangers, gas pressure vessels			
Pressurized Electronic System Components	1.00	1.10	1.50
Containers (black boxes) and battery boxes.			

(R) d. Thermal Loads

	Limit	*Minimum Proof	Ultimate
Thermal Loads/stresses	1.00	Not Applicable	1.00

(T) e. When substantiated by rational analysis that factors of safety lower than those listed above are consistent with attainment of specified probabilities of mission success/crew safety, such factors shall be substituted. This does not apply to minimum proof safety factors.

B. Design Phases

(R) 1. Ground Phase

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

* Minimum value to be used at equivalent operating environment or paragraph II, A, 14 Definitions, whichever higher.

2. Prelaunch and Erection Phases

(R) The vehicle shall be capable of sustaining all prelaunch and erection design loads as specified in SAFSL Exhibit 30012.

3. Launch Phase

(R,T) The vehicle shall be capable of sustaining all design load conditions as may be experienced during launch operations as specified in SAFSL Exhibit 30012. Consideration shall be given to the loading and environment induced by abort during this phase.

4. Ascent Phase

(R,T) The vehicle structure shall be designed for the entire power flight environment as specified in SAFSL Exhibits 30003 and 30012. Consideration shall be given to the loading and environment induced by abort during this phase.

5. Orbit Phase

(R,T) The vehicle shall be designed for 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:

a. Maneuvering Loads

(R) Loads resulting from maneuvers for changing orbits, orbit adjust, 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.

b. Meteoroid Environment

(R) 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 Section 3.2.5.e of SAFSL Exhibit 30003. 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:

1) 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 in this paragraph.

a) Single Plate Wall

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

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

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

p_t is the weight density of the wall material, lb/cu inch

K_1 is the single plate 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.

b) Double Plate Wall

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

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

where

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

K_2 is the double plate wall effectiveness factor

[m, E_t, and p_t are defined above]

The effectiveness factor, K_2, depends on wall spacing and on whether or not an energy absorbing filler is used. The values of K_2 given in Table 1 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.

the thickness of the outer plate or shield must be from 15 to 25 percent of the total thickness required in order that optimum shield effectiveness and the values of K_2 listed in Table 1 can be applicable.

c) The penetration equations given in Paragraphs III.B. 5.b.1.(a) and (b) are primarily for aluminum alloy but are considered adequate for most conventional structural materials.

c. Radiation Environment

(R,T) The effect of both natural and artificial radiation environment shall be considered in designing the structure, radiators, solar panels, etc., including 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 SAFSL Exhibit 30003.

d. Other Environments

(R,T) Other environments, both natural and induced, to be used in the structural design of the vehicle are given in SAFSL Exhibits 30003 and 10011. All items and components shall be designed for the most severe environmental conditions with consideration of both operational and nonoperational states.

TABLE 1

EFFECTIVENESS FACTOR FOR DOUBLE PLATE

WALL CONSTRUCTION, K_2

CASE I

Two plates spaced h inches 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 inches 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 inches 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 $h = 2$.

APPENDIX I

EK DEVIATIONS TO SAFSL EXHIBIT 30044 STRUCTURAL CRITERIA
FOR LABORATORY VEHICLE FOR THE MOL PROGRAM

1. Under paragraph II-C, Applicable Documents and also paragraph II-A-2-a, MIL-HDBK-17, Plastics for Flight Vehicles shall not apply to EK until this document has been reviewed and agreed upon by EK.

2. Under paragraph II-C, Applicable Documents and also paragraph III-A, MIL-M-8555A, Missiles, Guided: Design and Construction General Specification for, 6 Oct. 1960 shall not apply to EK until this document has been reviewed and agreed upon by EK.

3. The following paragraphs are not directly applicable to EK:

   a. III-A.1.a. External and Internal Load Distribution, first paragraph (External loads).

   b. III-A.4.c. Aeroelastic Requirements - Does not apply by virtue of non-exposure of EK equipment to this environment.

   c. III-B.5.b. Meteoroid Environment - Not applicable by virtue of non-exposure.

4. The EK effort to accomplish the requirement or task shall be confined to EK equipment only. All information or other data necessary to accomplish said effort or task will be furnished by the customer or associate contractors as applicable.

   a. III-A.1.a. External and Internal Load Distribution - Second paragraph (internal loads).

   b. III-A.1.e. Dynamic Loads

   c. III-A.5 Thermal Requirements