ANNEX A

TITLE : STRUCTURAL DESIGN DIRECTIVES FOR MPLM MOUNTEDEQUIPMENT

For information only!

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1. INTRODUCTION

The structural design and verification methodology requested for the Equipment of the various MPLM subsystems (PTCS/ATCS/ECLSS/AVIONIC/MECHANICAL/etc..), is expressed in this technical note.
It represents an attempt to synthetize the main requirements to be fulfilled to ensure the MPLM Equipment structural design to be satisfactory for PDR (preliminary design review) and CDR (critical design review) data package delivery.

1.1 Scope

This memo intends to be a guideline to the structural design and verification for the MPLM Equipment, with reference to points(1) ,(2) "Structural Analysis Report" which comprises the following areas:

Point (1) Design loads/Dynamic Analysis
" (2) Strength/Stress Analysis
" (3) Fracture Mechanics Analysis
" (4) Micro Gravity Analysis

As far as the above Points (3), (4) are concerned, these points are not taken into account here, since they should be part of dedicated DRD's and related Technical Reports should be generated. However, the case of Fail Safe Analysis (stemming from Point (3) activities) can be implemented as part of Point (2) activities.

In case of requirements conflict between present Annex and [AD1] or [AD2], the AD's shall have precedence.

1.2 References

1.2.1 Applicable Documents

[AD1] SSP 30559 Rev. B dtd. 30, June 1994
International Space Station, Structural Design and Verification Requirements

[AD2] MLM-EQ-AI-.........TBD
MPLM Equipment Specification

1.2.2 Reference Documents

[RD1] SSP 50005 Rev. B dtd. 9, August 1995
International Space Station, Flight Crew Integration Standard (NASA-STD-3000/T)

2. OUTPUT REQUESTED FOR PDR & CDR PHASES

2.1 Output for PDR

The following output is requested at PDR:

a) Engineering drawings
showing the following:
° the design philosophy
° mechanical interfaces

° detailed design solutions
° nominal dimensions
° materials
° standard parts

In addition, the design requirement for 'corners, edges, protrusions' for those equipment which are accessible to crew members shall be satisfied, as per [RD1].

b) Potential Fracture Critical Item List
showing the following:
° description of items
° drawing number
° material & process
° typical thickness
° failure mode
° type of load/stress
° max. stress
° verification approach type (safe life / fail safe / containment / low risk / low mass /)
° NDI method

c) Structural Analyses (modal/ loads/ stress/ fatigue)
See description within para 3.

2.2 Output for CDR
The following output is requested at CDR:

a) Manufacturing Drawings
same type of output as requested in para 2.1 point a), also including part list and information about manufacturing in integration

b) Potential Fracture Critical Item List
same type of output as requested in para 2.1 point b).

c) Structural Analyses (modal / loads / stress / fatigue /)
same type of output as requested in para 2.1. point c).

3. STRUCTURAL ANALYSIS TASKS

3.1 Modal Analysis
The modal analysis shall be performed in order to provide to the MPLM Project the following information:

a) Compliance with the 'minimum required stiffness' of the Equipment
b) Identification of global modes of vibration of Equipment

The modal analysis shall be considered satisfactory, if will be performed up to a frequency cut-off which guarantees that at least 80% of the modal mass for each direction (x,y,z) is participating to the dynamic behaviour. Global modes will be considered as those modes, whose participating mass for each direction is defined to be higher than 5%; only Global modes shall be considered for the evaluation of the random excitation response of the Equipment.

The modal analysis output shall comprise:
° Mathematical model description
° Eigenvaectors / Modes plot
° Eigenvalues / Effective masses
° Global modes description

The dynamic models shall be verified/checked during the Equipment qualification tests, by means of low level sine sweep tests, unless otherwise specified.

3.2 Load Analysis

The following loads and loads combinations shall be considered during Equipment design:
a) Fabrication
b) Testing
c) Transportation
d) Flight(lift-off, ascent, on-orbit, descent, re-entry, landing)
e) Emergency landing
f) Crew-applied loads
g) Pressure
h) Thermal.
i) Other TBD loads if requested by [AD2]

Table 3.2-i, in the following, indicates the typical environments which are applicable to each mission phase:

Environment -------------- Mission Phase	Quasi Static Low Trans.	Random	Acoustic	Crew Induced Loads	Thermal	Pressure	Shock
TRANSPORT.	x						x
LAUNCH & ASCENT	x	x	x			x	
ON-ORBIT				x	x	x	
DESCENT	x				x	x	
LANDING (nominal)	x				x		
LANDING (emergency)	x				x		

Table 3.2-i MPLM Equipment Mission Phases Environments

3.2.1 Design Loads Requirements

The essential criteria for design of Equipment to meet both STS and ISSA requirements are design loads which assure adequate structural integrity.
This section describes these design loads requirements, tells the Equipment Developer where to get specific data, and gives guidelines for the calculation of these data.
The Equipment related environments and loads requirements are reported in the Equipment specification, [AD2]; specific rules of treating these loads and their combination are reported in the following.

3.2.1.1 Quasi Static & Low Transient Accelerations

The combination of accelerations deriving by quasi static accelerations (rigid body accelerations) & low frequency transients (variable loads with a frequency up to 50 Hz) is represented by the QSL (quasi static load factor) which is a translational acceleration in the +x, -x, +y, -y, +z, -z. The QSL are obtained as an enveloping output of the MPLM latest results of C.L.A. (coupled load analysis), usually carried out for STS-MPLM lift-off & landing cases.

From [AD2], QSL = 10 g for x,y,z MPLM directions.

3.2.1.2 Random Vibration

The random vibration accelerations acting at Equipment C.o.g., result from the resonant structural response of the Equipment itself to random vibration input from STS mechanically and acoustically induced vibrations during launch.

Specific random vibration input levels at the I/F of the Equipment with its supporting structure, are given by [AD2] in terms of PSD (power spectral density).

Equipment random vibration acceleration reponses shall be calculated using the following procedure:

a) By calculation or test, determine the first global mode F_n of the Equipment (see note: @) for each coordinate axis x,y,z.

b) Determine the resonant amplification factor, "Q"
- ° from test data, if available
- ° estimated to be Q=10 if no data is available.

c) Using the F_n, Q and the PSD corresponding to F_n (see note: @@), the limit acceleration G_{peak} induced by the input spectrum shall be determined for each axis x,y,z, by using the Miles equation:

$$G_{r.m.s.} = [(\pi/2)*Q*F_n *PSD]^{1/2}$$

$$G_{peak} =3*G_{r.m.s.} \qquad (g)$$

being: G_{peak} the limit acceleration under which the Equipment C.o.g. is subjected to.
$G_{r.m.s.}$ the root mean square of the response under which the Equipment C.o.g. is subjected

The factor of 3 in above equation is applied since the calculated responses represent (1) one standard deviation, while the design limit accelerations include(3) three standard deviations.

(note:@) In case that, for a certain direction, F_n is the first natural frequency but is not deemed a global mode of vibration, then the first global mode shall be considered for random response calculation.

Alternatively, a less conservative approach could consist to evaluate an averaged peak response Gav_{peak} among all global modes by considering the weighted mean over the corresponding effective modal masses:

$$Gav_{peak} = 3* Gav_{r.m.s}$$

with:

$$Pi = Gi_{r.m.s.} * Mi_{eff.} \qquad (N)$$

$$Gav_{r.m.s} = [(\Sigma\ Pi^2)^{1/2}]/\Sigma\ Mi_{eff.}$$

where:

P_i	(N)	force level induced by i th. global mode
$Gi_{r.m.s.}$	(g)	r.m.s. acceleration level induced by the i th. global mode
$Mi_{eff.}$	(kg)	effective mass of the i th. global mode.
$Gav_{r.m.s.}$	(g)	averaged r.m.s. acceleration response at Equipment C.o.g.
Gav_{peak}	(g)	averaged limit acceleration response at Equipment C.o.g.

(note:@@) If F_n falls on a sloped portion of the PSD data, the PSD curve can be interpolated by using the following relationship:

$$PSD_n = PSD_{n1} * 10^Y \qquad (g^2/Hz)$$

with: $Y=[1/((\log 2)*10)]*S*\log(F_n / F_{n1})$

where:

S (Db/octave)	the slope of the PSD function (Db/oct.)
F_{n1} , PSD_{n1}	known parameters existing at one of the two extreme sides of the sloped part.
F_n	known frequency at point of interest of the sloped portion
PSD_n	PSD to be calculated at point of interest of the sloped portion.

3.2.1.3 Acoustic

N/A

Note: Acoustic loads for those Equipment MPLM internally mounted are negligibles.
Acoustic loads for those Equipment MPLM externally mounted having an 'm/a' Ratio (mass:area Ratio) lower than 3 kg/m^2 could be subjected to relevant acoustic pressures i.e. (solar panels, antennas, etc..).

3.2.1.4 Crew Induced Loads

The crew induced loads, in case of Equipment exposed to the crew, are reported in [AD2]; major information about all possible cases of crew induced loads, are reported in [RD1].

3.2.1.5 Thermal

The thermal environments for MPLM Equipment are reported by the [AD2] for both operating and non operating conditions.

As general approach, for MPLM internally mounted Equipment whose min./max. temperature range is quite limited, because of safety requirements like: dew point temperature, touch temperature, etc.., the structural effects of thermal field shall be taken into account as a corresponding decrease of the structural strength (yield / ultimate / fatigue) of materials w.r.t. their room temperature strength.

For the particular cases of MPLM space exposed Equipment (if any), where strong temperature ranges & gradients are existing, the structural effects induced by thermal gradients & thermal expansion of structures shall be superposed with the other applicable simoultaneous environments.

3.2.1.6 Pressure

The Equipment common pressure load condition occours in both ascent/descent and on-orbit environments and results in a depressurization/repressurization phase, such that the existing Equipment Enclosures shall be properly vented based on the MPLM pressurization/depressurization rate which is given in [AD2].

The minimum total venting area shall be in accordance with the enclosure structural capability.

Moreover, for those MPLM Equipment operating with pressurized fluids, the structural effects for these pressure loads shall be assessed, by analizing the pressure levels operating/ non operating/ test levels / reported in [AD2].

The pressure structural effects shall be superposed with the other simoultaneous environments.

3.2.1.7 Shock

N/A

Note: Shock loads from Ground phases/ transportation / ferry flight /are encompassed by the QSL.

3.2.2 Design Accelerations

3.2.2.1 Design Accelerations for Lift-off/Launch

The design accelerations for Lift-off , whose application matrix is shown in Tab. 3.2.2.1-i, are derived by adding, for each axis, the QSL's (simoultaneously for x,y,z) to the random vibration accelerations (one axis by time) by considering the following method, which represents a conservative application of the requirement of Table 3.5.1.3-1 of [AD1], (in cases that only QSL's are available).

These loads environments shall be obtained by the worst-case combination of QSL's and RV in x,y and z axes. A number of 24 basic load cases should be generated.

However, in case of low stressed structures, in order to save time and tedious calculations, a conservative reduction to only 3 basic load cases could be performed instead of above mentioned 24 load cases (by considering the superposition of effects induced by absolute values of accelerations).

Very common practice is to perform three "1g" runs, an then combining outputs stresses/loads/ etc. by means of linearity.

DESIGN LIMIT Acceleration Sets & (Cases)	x	y	z
1 (cases 1......8)	+/- (QSL+RV)	+/- QSL	+/- QSL
2 (cases 9.....16)	+/- QSL	+/- (QSL+RV)	+/- QSL
3 (cases 17...24)	+/- QSL	+/- QSL	+/- (QSL+RV)

Tab. 3.2.2.1-i Design Accelerations sets/cases for Lift-off/Launch

3.2.2.2 Design Accelerations for Landing

The design accelerations for Landing are considered to be a combination of the QSL's only. These loads environments can be obtained by the worst-case combination of QSL's in x,y and z axes simoultaneously. Since QSL's have been made applicable for all mission phases, then the Landing load cases will be encompassed by the Lift-off/Launch condition.

3.2.2.3 Design Accelerations for Emergency Landing

The design accelerations for Emergency Landing have to be considered as ultimate levels and can be applied separately to each axis. Since QSL's have been made applicable for all mission phases, then the Emergency Landing load cases will be encompassed by the Lift-off/Launch condition.

3.2.2.4 Design accelerations for Transportation/Ascent/On-orbit/Descent/

The design acceleration for Transportation/Ascent/On-orbit/Descent/, which show lower acceleration levels w.r.t. QSL, will be encompassed by Lift-off/Launch condition. Obviously for the Ground Operation cases, the above mentioned condition will be satisfied by a good performance of the MGSE design.

3.2.3 Factorization/Superposition of Load Types

The loads combination shall be performed based on simoultaneity of applicable environments to each mission phase.

Factors of safety, as per Table 3.3.1-1 of [AD1] shall apply to mechanically / pressure and thermally induced strains and stresses; however not to temperature, temperature gradients and friction.

When thermally induced strain/stresses are a relief, they shall not combined to the other load cases.

For combined loads, the resulting load/stress shall be evaluated by adding load/stress cases, each one with its appropriate factor of safety.

For fatigue cumulative damage calculations, the temperature cycling should not be superposed with acceleration cycling or pressure cycling because of different order of magnitude among typical pressure, acceleration and temperature cycles.

3.3 Stress Analysis

The stress analysis shall be performed by using the loads figures resulting from para 3.2. A detailed stress report shall be produced and all margins of safety of the principal structural elements shall be positive. The stress analysis shall be based on minimum dimensions obtained from tolerances on the drawings.

The following typical information shall be part of the stress analysis:

a) Introduction

b) References

c) Summary of analysis results
- summary of margins of safety
- summary of fundamental frequencies
- summary of interface loads

d) Hardware / Model Description
- interfaces description
- mass properties summary

e) Dynamic Analysis Results

-summary of frequencies and participating masses and modes

f) Load Environments

-environmental conditions
-temperature/pressure ranges & gradients
-lift-off and landing load cases
-summary of combined load conditions

g) Design Criteria

-factors of safety (in accordance to [AD1])
-methods/criteria (from good engineering practice), etc...

h) Material Properties

-room temperature material properties
-low & high operating temperature material properties

i) Potential Fracture Critical Items List

-(information list as required in paras 2.1 / 2.2)

k) Drawings

- drawings
-sketches related to calculations

j) Stress Analysis Calculations

-stress anayses (i.e.flange bending / bolts failure & tension & preload / bearing /shear out / collapse / etc.)
-margins of safety for the most critical areas

3.4 Fatigue Analysis

Fatigue analysis shall be performed for MPLM Equipment

The fracture control requirement ' safe life approach' which is based on the assumption that microscopic cracks exist whose growth to incipient failure must not occur within the useful life cycle of the structural component, encompasses and envelopes fatigue life requirements; therefore, in this case, the data submittal requirements for fracture control satisfy fatigue life requirements.

For the ' fail safe approach ', a fatigue life analysis is required to affirm that Equipment function and survivability, all concurrently occurring loadings must be considered and rationally combined to represent a conservative appraisal of the loading during each successive design loading event. Analysis must include the combined effects of static loading, low frequency and high frequency loading.

In any event, if basic strength analysis shows that the magnitude of the combined limit stress is less than the endurance limit of the material, infinite fatigue life is assured.

From Miner rule, the following life factors shall be used to take into consideration the interaction of quasi static + low frequency transients & random vibration:

$$\Phi_F = (\Phi_{L.F.}+\Phi_{R.V.})*S.F.= <1.0$$

where: Φ_{LF} = quasi static + low frequency transients fatigue damage
Φ_{RV} = random vibration fatigue damage
S.F. = scatter factor (S.F.=4)

The fatigue damage Φ is evaluated by a linear damage accumulation:

$$\Phi = \Sigma(n_i/N_{fi})$$

where: n_i is the actual number of cycles at a particular stress or strain amplitude, and N_{fi} is the number of cycles to failure at the same amplitude (Miner's Rule).

The two categories of stress to be considered in a fatigue analysis are:

°) Alternating stress: any stress which changes as a function of time and flight event; (typical examples are stress results from low frequency transients and random loads).

°°) Mean stress: any constantly applied stress.

Constant life fatigue may be used with the combined mean and alternating stresses when available. When not available, the modified Goodman rule may be used, as represented by the formula:

$$\sigma_E=\sigma_A/(1-\sigma_M/S_U)$$

where:

σ_E = Equivalent pure alternating stress ($R=-1=\sigma_{min}/\sigma_{max}$)
σ_A = True alternating stress $=(\sigma_{max} - \sigma_{min})/2$
σ_M = True mean stress $=(\sigma_{max} + \sigma_{min})/2$
S_U = Ultimate tensile strength of the material

Classical fatigue analysis theories and fatigue parameters (i.e. stress intensification factors, notch sensitivities, etc..) shall be used.

Fatigue factors shall be implemented in accordance to para 3.5.7.2 of [AD1] .

In cases of existing creep stress and the creep damage (Φc) is deemed relevant, then Φo (creep + fatigue) overall cumulative damage will be considered, based on the following relationship:

$$\Phi o = \Phi_F + \Phi c < 1.0$$

Fatigue Exposures:

The MPLM Equipment shall be subjected to a number of 25 missions.

The low frequency loading, beginning at SSME (Space Shuttle Main Engine) ignition, should have a duration profile of type shown in Table 3.4-i.
In any case, the maximum exposure expected for each single MPLM mission shall be less than 309 seconds, such that based on some simplified conservative assumptions, the Equipment shall be subjected to a maximum number of 77250 QSL's cycles over 25 MPLM missions (very conservative hypothesis).

A random loads exposure of 810 seconds (60 sec. +25 miss. x 30sec./miss.) shall be considered for each excitation axis, for those Equipment which are not life-limited.

The fatigue analysis of Equipment that are life-limited (if any), must demonstrate a calculated life for random vibration of 60 seconds for the first mission plus 30 seconds for each additional mission; however, a minimum exposure of 180 seconds shall always be considered.

The cycling due to high frequency random vibrations, will be a Rayleigh type probability distribution, as shown in Table 3.4-ii.

A conservative example of cycles discretization for the random vibration response is given by considering the Rayleigh Distribution Exceedance Cycles :

$N(1\sigma)$=39.3%; $N(2\sigma)$=47.2%; $N(3\sigma)$=13.5%;$N(4\sigma)$=n/a.

Fatigue Levels:

The fatigue contribute for quasi static and low transients acceleration shall conservatively consider a QSL (Quasi Static Load Factor) of 10 g for each excitation axis.
The fatigue levels for random vibrations will be a Rayleigh type probability distribution.
The random vibration 'limit response' is defined being the 3σ level.

Despite to the static loadings case, for fatigue analysis the QSL's and random fatigue loading shall be analyzed separately both in terms of cycles and amplitude, after that, their single cumulative damage will be superposed with Miner rule; (this assumption is due to the fact that is not credible a significative number of repeated events where both QSL and random loads are in the worst fatigue condition).

Note: For those Equipment which satisfy one of the following two conditions:
1) The RV along each axis is higher than 3 times the QSL's (RV> 30 g peak).
2) The fundamental frequency of the Equipment (subjected to a Qualification Spectrum not lower than QAVT (7.9 rms.)) being higher than 100 Hz.

then, the corresponding QSL's contribute to the fatigue cumulative damage can be considered negligible.

CONDITION	TIME (seconds)
LIFT-OFF	9
HIGH Q BOOST	35
MAX. BOOST	35
ORBITER MAX. LOAD	100
ENTRY AND DESCENT MANEUVERS	
+/- PITCH	120
+/- YAW	120
+/- ROLL	120
LANDING	10

Table 3.4-i Flight duration time per mission for low frequency fatigue assessment

FORMULATION	$D(\sigma)=e^{-(\sigma*\sigma/2)}$	$p(\sigma)=D(\sigma)*\sigma$
Description of Function	Probability Distribution	Probability Density

Table 3.4-ii Rayleigh Probability Function for random vibration response.

4. STRUCTURAL MODELS

Structural models (simplified & FEM) shall be prepared for both PDR and CDR Phases, to demonstrate the compatibility of the Equipment with the STS system.

4.1 Simplified Models

Simplified models (computerized models/ hand calculation models/ etc..) shall implement good engineering practice.

4.2 FEM

FEM (finite elements models) shall represent with sufficient detail the overall structure.
The structural analysis shall be performed by using one of the most common used FEM codes (i.e. NASTRAN/ANSYS/PATRAN/SUPERSAP/etc).

4.2.1 FEM Inputs

The minimum information required for a FEM model, shall be as follows:

a) Description of the structure: to define the nomenclature and inter-relation of the modelized components of the overall structure. Isometric and exploded views are preferred for clarity.

b) Summary of the connectivity: (i.e. from NASTRAN, a table of this type):

Type of card	Total Number
GRID	N1
CQUAD4	N2
CELAS2	N3
....	...

c) Philosophy of numbering: to explain the logic used for numbering nodes and elements. Global ranges for nodes, elements, loads, constraints and cases of analysis shall be provided.

d) Units: the system of units adopted and symbols must be specified.

e) Coordinate systems: a description of the coordinate system used.
The following information shall be indicated:
- comparison between MPLM coordinate system and FEM coordinate system
- label number
- type(rectangular,cylindrical, spherical)
- origin of coordinates

f) Assumptions and idealizations: a detailed list about the main assumptions and idealizations.

g) Boundary conditions: a description of the constraints (i.e. from NASTRAN single/multi point constraints); plots and sketches can be used to simplify the description.

h) Mass distribution: a description of how the mass of the structure is included in the F.E.M. It shall comprise the following:
° structural mass and density
° lumped masses
° distributed non structural masses
° total mass and C.o.g. position (i.e. the output from NASTRAN Grid points weight generator shall be included).
° comparison of the plots and design drawings to show the difference between model and actual design.

i) Loads: an organic and clear summary of the load sets that have been considered.

j) Properties and materials: a table reporting the FEM code cards commented and referred to a sketch representing the geometrical properties of cross sectional area of each structural element.

k) Listing of the model.

l) Plots of the model.

4.2.2 FEM Outputs

FEM outputs (plots / numerical / etc..) derived from structural tasks shall be reported within the Structural Data Package, providing the following minimum information.

- Reaction loads results
- Maximum stress levels result
- Eigenvalues analysis results

5. FAIL SAFE ANALYSIS

5.1 Fail Safe Philosophy

A part is defined as fail-safe if it can be shown by analysis or test that, due to the structural redundancy, the structure remaining after failure of the one part can sustain the new, higher limit loads with an ultimate factor of safety equal or greater than 1.0, and the remaining structure has sufficient fatigue life to complete the mission. In addition, the failure of a part shall not release fragments that could cause catastrophic event into habitable areas. Only one failure at a time need to be considered; hazards caused by the failure of two or more parts in series need not be considered.

If significant, the analysis or test shall consider the higher loads on the remaining structure caused by redistribution of loads following failure of the part and/or the altered dynamic characteristics of the structure caused by the failure of the part.

The fail safe criterion shall not be used to show compliance for pressure vessels or rotating machinery and all other members which are subjected to different Fracture Mechanics Approaches.

5.2 Required Tasks

Eventhough fail safe analysis has to be considered as an activity of the 'Fracture Control' along with the following activities: /safe-life/low mass/containment/restainment/, usually, the fail safe task is carried out along with the structural analysis tasks, and obviously implemented into the 'Structural Analysis Report', by utilization of the common structural models.

Thus, in case of applicability of fail safe analysis to an Equipment, all possible cases of Fail safe shall be considered over the original structural configurations.

6. FACTORS & MARGINS OF SAFETY

6.1 Factors of Safety Definition

The factor by which the limit load is multiplied to obtain the ultimate or yield load. The limit load is the maximum anticipated load or combination of loads, which a structure may be expected to experience. Ultimate and yield load is the load that an item must be able to withstand without failure.

6.2 Factors of Safety Application

The MPLM Equipment shall be designed with the application of factors of safety whose list is reported in Table 3.3.1-1 of [AD1].

6.3 Margins of Safety Definition

The parameter utilized by the structural discipline to express structural capability in terms of structural requirements which include factor of safety.
Margins of safety are expressed for both yield and ultimate criteria.

The basic equation defining margin of safety for uniaxial stress (which does not apply for combined stresses) is:

$$MS = \frac{\text{allowable stress/force (yield/ultimate)}}{\text{FS (yield/ultimate)} * \text{limit applied stress/force}} - 1$$

6.4 Margins of Safety Evaluation

All MPLM Equipment mechanical items shall have positive margins of safety (MS>0) for all envisaged load conditions/combinations using the applicable factors of safety.

6.5 Margins of Safety for Fatigue/Creep

Margins of safety for fatigue & creep analysis may be expressed both in two different ways depending on the type of method used for fatigue/creep analysis:

a) If Miner theory is applied by means of (Wholer or Goodman curves), then margins of safety shall be expressed in terms of damage ratio.

b) If Stress comparison is applied by means of (i.e. Smith curves/ Goodman equation for equivalent stress), then margins of safety shall be expressed in terms of stress ratio.