APPENDIX B

CONTAINMENT

B.1 Containment. This appendix provides methods of containment for parts that may come loose during rotation and more generally for parts that may come loose inside of "containers" such as electrical boxes during payload acceleration for launch or landing. These methods used the "Punch" equation from Reference 21. Various formulae have been developed by investigators to assess containment. Of these, the Punch equation has been favored for use in containment assessments of enclosed loose parts on payloads and is supported by a limited amount of test data. The Punch equation is based on data generated to establish the energy required to "punch out" various sizes of circular areas in metals with given thickness and tensile yield strength. Use of penetration equations involves some degree of subjectivity, but the Punch equation is accepted as conservative. In addition to the container penetration analysis, it is sometimes necessary to address the fasteners that hold the container together. The Punch equation application to rotating parts is addressed in Section B.2, to general parts in Section B.3, and whether or not a fastener analysis is required and some things to consider in such an analysis are addressed in Section B.4.

B.2 Containment of Rotating Parts. Fracture control requirements for operational safety of rotating devices often necessitate an evaluation of containment capability of covers, rings, housings, etc., which surround a rotating part such as a fan, motor, gyroscope, etc. For extremely high rotational velocities, other additional considerations such as rubbing will likely need to be considered to help dissipate the energy. The Punch equation may be written as follows:

$$T = \left[\frac{MV^2}{2\pi D F_{ty}} \right]^{1/2} \qquad \text{(B1)}$$

F_{ty} = Tensile yield strength of the container
D = Diameter of the projectile
M = Mass of projectile
T = Thickness required to contain the projectile
V = Impact velocity

An effective diameter for other than circular impact shapes may be determined by relating the perimeter length of the predicted impact area and shape to a circle with an equal perimeter having a diameter D′. D′ may be substituted for D in the equation. The predicted area and shape is based on the entire frontal face of the part assumed normal to the container on impact.

A conservative estimate of the impact velocity V to be substituted into equation B1 can be calculated by the following:

$V = r\omega$ where: r = outer radius of the rotating part (B2)
ω = rotational speed of the rotating part

If the calculated "T" is larger than the actual enclosure thickness then the rotating part will not be contained in the event of fragment generation of the shape, size and mass assessed. A rotating part, which would not be contained, must be assessed for safe life using a conventional fracture mechanics approach.

B.2.1 Sample Calculation. A small 2 (two) blade cooling fan has a diameter of 3.06 inches. The fan weighs 0.302 lbs (137 gms) and rotates at 10,000 rpm (1047 rad/sec). The fan and its housing are made of 6061-T6 aluminum alloy. The blades are 0.07 inch thick and the housing is 0.1 inch thick. Calculations show that the rotating fan does not possess the energy level necessary (14,240 ft-lbs) to automatically require proof testing, inspection and safe life assessment. Because of high rpm, an analysis must be made for containment.

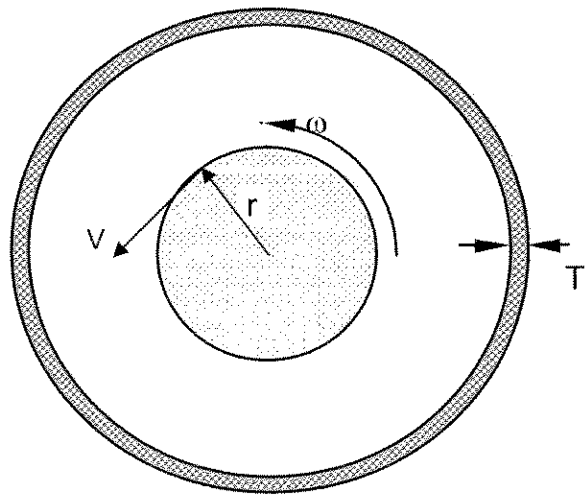

FIGURE B-1. Analytical Sketch for Rotating Hardware

$V = r\omega = (1.53 * 1047) = 1602$ in/sec

Weight of the released blade from the two blade fan is assumed to be ½ of the fan weight (conservative) = 0.151 lbs

Gravitational acceleration, $g = 32.2$ ft/sec^2 = 386.4 in/sec^2

Mass of the fan blade = 0.151/386.4 = 0.00039 lb-sec^2/in

Impacting edge of the blade is assumed to be 1 inch long.

Perimeter of the blade = $[(2 * 1.0) + (2 * 0.07)] = 2.14$ inches

Diameter of the circle with a circumference of 2.14 in = $2.14 / \pi = 0.68$ inch

Therefore, $D' = 0.68$ inch

Tensile yield strength (F_{ty}) for Al 6061-T6 is taken to be 35,000 psi

Calculation: $$T = \left[\frac{(0.00039 lb - \sec^2/in) * (1602 in/\sec)^2}{2 * (\pi) * (0.68 in) * (35000 lb/in^2)} \right]^{1/2} = 0.082 \text{ inch}$$

Conclusion: Required T = 0.082 inch and Actual T = 0.1 inch

Therefore, break-up of the fan is contained.

B.3 General Containment. Containment analyses should consider such factors as the velocity and energy of the part, worst-case sharpness/minimum area, elastic and/or plastic deformation, and the resulting stresses on the enclosure.

For containment, it must be shown that structures or parts will be contained in the event that they become detached from the payload because of structural failure of the part or attachment fasteners. Analysis must show that no part can attain sufficient kinetic energy to escape a container, which completely encompasses the aggregate structures or parts (such that none of them or their fragments can escape the confines of their container to cause a hazard to the STS/ISS or crew). The "Punch" equation used to show no penetration of the container wall is taken from Reference 7 and the procedure given here is a modification of Reference 21.

Equation B1 is rewritten as:

$$T = \sqrt{\frac{V^2 W}{2\pi D g F_{ty}}} \quad \text{(B3)}$$

$$V = V_1 + V_0 \quad \text{(B4)}$$

$$V_1 = \sqrt{2 a S_d} \quad \text{(B5)}$$

$$V_0 = \sqrt{\frac{2U}{\left(\frac{W}{g}\right)}} \quad \text{(B6)}$$

$$U = \frac{P_0^2 L}{2AE} \quad \text{(B7)}$$

Where,

T =	The minimum required wall thickness (inches) of the container to prevent escape of the component/part.
V =	Impact velocity (in/sec) of the detached piece or part.
W =	Weight (pound-force) of the detached piece or part to be contained or ½ weight of fastener when considering the detached piece to be a fractured fastener.
D =	Minimum profile diameter (inches) of piece or part that will impact the container wall.
g =	Gravitational acceleration (in/sec^2)
F_{ty} =	The tensile yield strength (pounds per square inch) of the container wall material.
V_1 =	Impact velocity (in/sec) of detached piece due to acceleration.
a =	Acceleration (in/sec^2) that produces V_1. It is acceptable to use 1255 in/sec^2 (3.25 g, orbiter boost, Max N_x, Table 4.1.3.1-1 of Reference 34) for launch and landing.
S_d =	The maximum travel distance of the projectile within the container (such as the longest diagonal in a rectangular box, minus the smallest dimension of the free part).
V_0 =	Impact velocity (in/sec) due to fracture of a preloaded fastener. This would generally apply to a low fracture toughness fastener weighing more than 0.03 pounds, otherwise the fastener could be classified as low released mass.
P_0 =	Fastener preload in pounds.
U =	Fastener stored energy (in-lb) due to preload.
L =	Fastener preloaded length in inches.
A =	Fastener cross sectional area in inches^2.
E =	Fastener modulus of elasticity (lb/in^2).

B.3.1 Minimum Effective Impact Diameter. For objects, which have no circular cross section, a diameter equivalent to a round projectile has to be calculated using the smallest possible projected perimeter for any angular orientation of the object. Examples follow:

A. πD = Perimeter of the smallest face of a rectangular object (2 x (length +width).
B. πD = Perimeter of the circular projection when looking at a conical end.
C. πD = The base perimeter of a cone.
D. πD = The perimeter of the projected flat edge of a disk (2 x (diameter + thickness)).

B.3.2 Projectile Velocities. The kinetic energy of the projectile(s) created as a result of a structural failure of contained structures or parts is determined by the mass of the detached part (M) and the velocity (V) it can attain within the confines of its container. Contributors to the projectile impact velocity that the analyst should consider are:

- The impact velocity (V_1) due to acceleration.
- Initial velocity (V_0) of a fastener fragment caused by the sudden release of preload.

Neither the relative velocity due to the structural dynamic response of the projectile and its mounting prior to release, nor the relative velocity due to the vibration response of the impacted wall is generally considered in the velocity calculations. These components are required only for special cases of significant structural displacements sufficient to generate a whip type action propelling the projectile or wall displacements that are an order(s) of magnitude times the thickness. If the analyst is unsure about the need for their inclusion, the RFCA should be consulted.

If the failure is that of a preloaded fastener, then the initial velocity, Vo, will be induced by the sudden conversion of stored energy (preload) to kinetic energy. This projectile velocity is given by equation B6 and should be included in the calculations for low fracture toughness fasteners that exceed 0.03 pounds.

B.4 Container Fastener Analysis. As stated earlier, it is sometimes necessary to address the fasteners that hold the container together. For example, the fasteners that hold the lid on a box may require analysis to show that they would not break in the event that the lid is impacted by a loose part. Both rotating and stationary parts should be assessed for the need of this check.

This assessment would be required for containment of a relatively large mass with a relatively large contact area whose impact would not be expected to penetrate the walls, but would nonetheless be a significant dissipation of energy. This check is not required for electronics and similar boxes using standard packaging designs. So, it is anticipated that the analyst will only rarely be confronted with situations where this analysis is warranted. The analyst should coordinate with the RFCA when uncertainty exists for analyzing container fasteners.

This type of analysis can be quite complex and involve several failure modes. Some of the things to consider are:

a. Does the loose part strike at a single fastener or between fasteners?
b. Does the fastener fail in tension or extrude the fastener head through the wall thickness?
c. If a fastener fails, will adjacent fasteners carry the remaining energy?
d. If a fastener(s) fails, will the deflection of the cover remain small enough so that the loose part does not escape?
e. Does the loose part absorb significant energy itself upon impact with the container wall?

A simplified method for assessing the tensile capability assuming a loose part impacts directly upon a single fastener is given below. This is conservative since a loose part is most likely to strike in an area where the load would be shared among more than one fastener. If the fastener passes this check, a similar check would be required for extruding the fastener head through the cover wall. If both these checks are passed, the analysis would generally be considered complete; otherwise, the analyst must investigate further the type of things listed above.

The approach is to assume that the kinetic energy of the loose part must be absorbed by the strain energy capability of the fastener. This kinetic energy is readily available from the analysis completed in Section B.2 or Section B.3 from which the mass and impact velocity are known.

$$K.E. = \frac{1}{2} m V^2 \qquad \text{(B8)}$$

Where,
$K.E.$ = Kinetic energy of the loose part (in-lb)
m = Mass of the loose part (lb sec^2/in)
V = Impact velocity of the loose part from equation B2 or B4 (in/sec)

An acceptable estimate of the allowable strain energy of a bolt in tension can be calculated from:

$$S.E. = \varepsilon_{ult}\, l \frac{P_{ty} + P_{tu}}{2} \qquad \text{(B9)}$$

$S.E$ = Strain energy capability of the bolt (in-lb)

ε_{ult} = Ultimate strain capability of the bolt material (in/in)

l = Length of the bolt strained in tension (in)

P_{ty} = Tensile yield strength of the bolt (lb)

P_{tu} = Tensile ultimate strength of the bolt (lb)

The loose part with the maximum kinetic energy would be chosen. This would be easily determined from the work already done in Section B.2 or Section B.3. This kinetic energy would be calculated using equation B8 and compared to the strain energy capability determined from equation B9 for the weakest fastener holding the container together.

1.6K.E. < S.E. is necessary for containment, where 1.6 is a dynamic amplification factor.