METHOD 513.8

ACCELERATION

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METHOD 513.8

ACCELERATION

NOTE: Tailoring is essential. Select methods, procedures and parameter levels based on the tailoring process described in Part One, paragraph 4.2.2, and Annex C. Apply the general guidelines for laboratory test methods described in Part One, paragraph 5 of this Standard.

1. SCOPE.

1.1 Purpose.

The acceleration test is performed to assure that materiel can structurally withstand the steady state inertia loads that are induced by platform acceleration, deceleration, and maneuver in the service environment, and function without degradation during and following exposure to these forces. Acceleration tests are also used to assure that materiel does not become hazardous after exposure to crash inertia loads.

1.2 Application.

This test Method is applicable to materiel that is installed in aircraft, helicopters, manned aerospace vehicles, air-carried stores, and ground/sea-launched missiles.

1.3 Limitations.

1.3.1 Acceleration.

As addressed in this Method, acceleration is a load factor (inertia load, "g" load) applied slowly enough and held steady for a period of time long enough such that the materiel has sufficient time to fully distribute the resulting internal loads, and such that dynamic (resonant) response of the materiel is not excited. Where loads do not meet this definition, more sophisticated analysis, design, and test methods are required.

1.3.2 Aerodynamic Loads.

Materiel mounted such that any or all surfaces are exposed to aerodynamic flow during platform operations are subject to aerodynamic loads in addition to inertia loads. This method is not generally applicable to these cases. Materiel subject to aerodynamic loads must be designed and tested to the worst case combinations of these loads. This often requires more sophisticated test methods usually associated with airframe structural (static and fatigue) tests.

1.3.3 Acceleration versus Shock.

Acceleration loads are expressed in terms of load factors that, although dimensionless, are usually labeled as "g" loads. Shock environments (Methods 516.8 and 517.3) are also expressed in "g" terms. This sometimes leads to the mistaken assumption that acceleration requirements can be satisfied by shock tests or vice versa. Shock is a rapid motion that excites dynamic (resonant) response of the materiel, but with very little overall deflection (stress). Shock test criteria and test methods cannot be substituted for acceleration criteria and test methods or vice versa.

1.3.4 Climatic Conditioning.

Special provisions for performing combined acceleration/climatic environment tests (e.g., acceleration tests at high or low temperatures) may be required for certain operational tests. Guidelines found in the climatic test methods may be helpful in setting up and performing combined environment tests.

2. TAILORING GUIDANCE.

2.1 Selecting the Acceleration Method.

After examining requirements documents and applying the tailoring process in Part One of this Standard to determine where acceleration effects are foreseen in the life cycle of the materiel, use the following to confirm the need for this Method and to place it in sequence with other methods.

2.1.1 Effects of Acceleration.

Acceleration results in loads on mounting hardware and internal loads within materiel. Note that all elements of the materiel are loaded, including fluids. The following is a partial list of detrimental effects from high levels of acceleration. If there is expectation that any of these may occur, it confirms the need to test for this effect.

a. Structural deflections that interfere with materiel operation.

b. Permanent deformation, structural cracks, and fractures that disable or destroy materiel.

c. Broken fasteners and supports that result in loose parts within materiel.

d. Broken mounting hardware that results in loose materiel within a platform.

e. Electronic circuit boards that short out and circuits that open up.

f. Inductances and capacitances that change value.

g. Relays that open or close.

h. Actuators and other mechanisms that bind.

i. Seals that leak.

j. Pressure and flow regulators that change value.

k. Pumps that cavitate.

l. Spools in servo valves that are displaced causing erratic and dangerous control system response.

2.1.2 Sequence Among Other Methods.

a. General. See Part One, paragraph 5.5.

b. Unique to this Method. Examine the life cycle environmental profile to determine the test sequence. Normally, acceleration is experienced after logistic storage and transportation environments and often near the end of the life cycle. Shock, vibration, and thermal stressing prior to acceleration testing is recommended as this will uncover failures that would not occur with unstressed items.

2.2 Selecting a Procedure.

This Method includes three test procedures.

a. Procedure I - Structural Test.

b. Procedure II - Operational Test.

c. Procedure III - Crash Hazard Acceleration Test.

d. Procedure IV - Strength Test.

2.2.1 Procedure Selection Considerations.

Subject materiel to be tested to both Procedures I and II tests unless otherwise specified. Subject manned aircraft materiel that is located in occupied areas or in egress and ingress routes to Procedure III. Procedure IV is special case for strength testing materiel that cannot be assessed by Procedures I and II.

2.2.2 Difference Among Procedures.

2.2.2.1 Procedure I - Structural Test.

Procedure I is used to demonstrate that materiel will structurally withstand the loads induced by in-service accelerations.

2.2.2.2 Procedure II - Operational Test.

Procedure II is used to demonstrate that materiel will operate without degradation during and after being subjected to loads induced by in-service acceleration. Rationale for operational test levels can be found in paragaraph 6.1, reference k.

2.2.2.3 Procedure III - Crash Hazard Acceleration Test.

Procedure III is used to disclose structural failures of materiel that may present a hazard to personnel during or after a crash. This test is intended to verify that materiel mounting and/or restraining devices will not fail and that sub-elements are not ejected during a crash. Use for materiel mounted in flight occupied areas and/or that could block aircrew/passenger egress or rescue personnel ingress after a crash. The crash hazard can be evaluated by a static acceleration test (Method 513.8, Procedure III) and/or transient shock (Method 516.8, Procedure V). The requirement for one or both procedures must be evaluated based on the test item.

> Only when the system and/or attachment method has a natural frequency below the knee frequency of the shock SRS, might this test be required to supplement the Crash Hazard Shock Test (see Method 516.8, Figure 516.8-9). For planning purposes, Procedure III should be included for budgeting and scheduling consideration until it is shown by analysis or a laboratory test that this procedure isn't required.

2.2.2.4 Procedure IV – Strength Test.

Procedure IV is a strength test primarily intended to generate specific loads in primary structures using sine burst testing. This method may be used as an alternative to static pull or centrifuge testing and is suitable for testing relatively stiff components, electronics boxes, instruments, or space vehicles. The sine burst test is a base-driven test in which the test article is subjected to a few cycles (typically 2 to 10 at peak amplitude) of sinusoidal input. This is usually done below the first resonant frequency of the test article to expose the hardware to a quasi-static loading. An example test profile is shown in Figure 513.8-1.

2.3 Determine Test Levels and Conditions.

The tests vary in acceleration level, axis of acceleration, duration, test apparatus, and on/off state of test item. Obtain acceleration values for individual materiel items from the platform structural loads analyses. When the applicable platform is unknown, the values of Tables 513.8-I, 513.8-II, 513.8-III and 513.8-IV and the following paragraphs may be used as preliminary test criteria pending definition of actual installation criteria.

2.3.1 Test Axes.

For the purpose of these tests, the axes should be consistent with the sign convention and axes used in the structural analysis of the platform with the direction of forward acceleration of the platform. The test item is tested in each direction along three mutually perpendicular axes for each test procedure. One axis is aligned with the forward acceleration of the platform (fore and aft, X), one axis is aligned with the span-wise direction of the platform (lateral, Y), and the third axis is perpendicular to the plane of the other two axes (up and down, Z). Positive rotational axes and accelerations vary between platforms as they are typically determined by various means such as use of the "left hand" or "right hand rule." Figure 513.8-2 shows a typical vehicle acceleration axes system with sign convention defined by the "right hand rule".

2.3.2 Test Levels and Conditions - General.

Tables 513.8-I, 513.8-II, and 513.8-III & IV list test levels for Procedure I (Structural Test), Procedure II (Operational Test), and Procedure III (Crash Hazard Acceleration Test), respectively. When the orientation of the materiel item relative to the operational platform is unknown, the highest pertinent level applies to all test axes.

Table 513.8-I. Suggested g levels for Procedure I - Structural Test.

Vehicle Category [1]		Forward Acceleration A (g's) [2]	Test Level: Direction of Vehicle Acceleration (See Figure 513.8-2)					
			Fore	Aft	Up	Down	Lateral: Left	Lateral: Right
Aircraft [3], [4]		2.0	1.5A	4.5A	6.75A	2.25A	3.0A	3.0A
Helicopters		[5]	4.0	4.0	10.5	4.5	6.0	6.0
Manned Aerospace Vehicles [6]		6.0 to 12.0 [7]	1.5A	0.5A	2.25A	0.75A	1.0A	1.0A
Aircraft Stores Carried on:	Wing/ Sponson	2.0	7.5A	7.5A	9.0A	4.9A	5.6A	5.6A
	Wing Tip	2.0	7.5A	7.5A	11.6A	6.75A	6.75A	6.75A
	Fuselage	2.0	5.25A	6.0A	6.75A	4.1A	2.25A	2.25A
Ground-Launched Missiles		[8], [9]	1.2A	0.5A	1.2A' [10]	1.2A' [10]	1.2A' [10]	1.2A' [10]

[1] Use levels specified for individual platforms and locations on/in the platforms. Use the values of this table only if platform criteria are unavailable.

[2] Use levels in this column when forward acceleration is unknown. When the forward acceleration of the vehicle is known, use that value for A.

[3] For carrier-based aircraft, use 4 as a minimum value for A, representing a basic condition associated with catapult launches.

[4] For attack and fighter aircraft, add pitch, yaw and roll accelerations as applicable (see paragraph 2.3.3).

[5] For helicopters, forward acceleration is unrelated to acceleration in other directions. Test levels are based on current and near future helicopter design requirements.

[6] Manned vehicles capable of flight in the Earth's atmosphere and surrounding space environment.

[7] When forward acceleration is not known, use the high value of the acceleration range.

[8] A is derived from the propulsion thrust curve data for maximum firing temperature.

[9] In some cases, the maximum maneuver acceleration and the maximum longitudinal acceleration will occur at the same time. When this occurs, test the materiel with the appropriate factors using the orientation and levels for the maximum (vertical) acceleration.

[10] Where A' is the maximum maneuver acceleration.

Table 513.8-II. Suggested g levels for Procedure II - Operational Test.

Vehicle Category [1/]		Forward Acceleration A (g's) [2/]	Test Level: Direction of Vehicle Acceleration (See Figure 513.8-2)					
			Fore	Aft	Up	Down	Lateral: Left	Lateral: Right
Aircraft [3/, 4/]		2.0	1.0A	3.0A	4.5A	1.5A	2.0A	2.0A
Helicopters		[5/]	2.0	2.0	7.0	3.0	4.0	4.0
Manned Aerospace Vehicles [6/]		6.0 to 12.0 [7/]	1.0A	0.33A	1.5A	0.5A	0.66A	0.66A
Aircraft Stores Carried on:	Wing/ Sponson	2.0	5.0A	5.0A	6.0A	3.25A	3.75A	3.75A
	Wing Tip	2.0	5.0A	5.0A	7.75A	4.5A	4.5A	4.5A
	Fuselage	2.0	3.5A	4.0A	4.5A	2.7A	1.5A	1.5A
Ground-Launched Missiles		[8/, 9/]	1.1A	0.33A	1.1A' [10/]	1.1A' [10/]	1.1A' [10/]	1.1A' [10/]

[1/] Use levels specified for individual platforms and locations on/in the platforms. Use the values of this table only if platform criteria are unavailable.

[2/] Use levels in this column when forward acceleration is unknown. When the forward acceleration of the vehicle is known, use that value for A.

[3/] For carrier-based aircraft, use 4 as a minimum value for A, representing a basic condition associated with catapult launches.

[4/] For attack and fighter aircraft, add pitch, yaw and roll accelerations as applicable (see paragraph 2.3.3).

[5/] For helicopters, forward acceleration is unrelated to acceleration in other directions. Test levels are based on current and near future helicopter design requirements.

[6/] Manned vehicles capable of flight in the Earth's atmosphere and surrounding space environment.

[7/] When forward acceleration is not known, use the high value of the acceleration range.

[8/] A is derived from the propulsion thrust curve data for maximum firing temperature.

[9/] In some cases, the maximum maneuver acceleration and the maximum longitudinal acceleration will occur at the same time. When this occurs, test the materiel with the appropriate factors using the orientation and levels for the maximum (vertical) acceleration.

[10/] Where A' is the maximum maneuver acceleration.

Table 513.8-III. Suggested g levels for Procedure III - Crash Hazard Acceleration Test. [3/]

Vehicle/Category	**Test Level (g's)** [1/]					
	Direction of Vehicle Acceleration (See Figure 513.8-2)					
	Fore	**Aft**	**Up**	**Down**	**Left**	**Right**
All manned air vehicles except cargo/transport						
Personnel capsule	40	12	10	25	14	14
Ejection seat	40	7	10	25	14	14
All other items [2/]	40	20	10	20	14	14
Helicopters [4/]	20	20	10	20	18	18
Cargo/transport						
Pilot and aircrew seats	16	6	7.5	16	5.5	5.5
Passenger seats	16	3	4	16	5.5	5.5
Side facing troop seats	3	3	5	16	3	3
Personnel restraint	10	5	5	10	3	3
Stowable troop seats	10	5	5	10	10	10
All other items [2/]	20	10	10	20	10	10
Helicopters [4/]	20	20	10	20	18	18

[1/] Use levels specified for individual platforms and locations on/in the platforms. Use the values of this table only if platform criteria are unavailable.

[2/] The intent of this test is to disclose structural failures of materiel that may present a hazard to personnel during or after a crash. This test is intended to verify that materiel mounting and/or restraining devices will not fail and that sub-elements are not ejected during a crash. Use for materiel mounted in flight occupied areas and/or that could block aircrew/passenger egress or rescue personnel ingress after a crash.

[3/] Test item function is not required following this test. Thus test items that are not suitable for other tests or field use may be used for this test. Ensure test items are structurally representative (strength, stiffness, mass, and inertia) of the production design, but need not be functional. All contents (including fluids) designed to be carried in/on the materiel should be included. Tactical restraint systems should be loaded with the maximum expected weight.

[4/] See paragraph 6.1, reference a. Some system specific crash hazard acceleration levels are provided in Table 513.8-IV.

Table 513.8-IV. System specific g levels for Procedure III - Crash Hazard Acceleration Test.

AH-64 A & D Aircraft Crash Test Levels (g's) [1]					
Direction of Vehicle Acceleration	Applied Separately	Applied Simultaneously [6]			Transport Acceleration Applied Separately (items not able to reach cockpit)
Up	20	10	20	10	4.5
Down	10	5	10	5	2
Lateral	±20	±10	±10	±20	1.5
Forward	20	20	10	10	1.5
Aft	20	20	10	10	3
OH-58D Kiowa Warrior Aircraft Crash Test Levels (g's) (Applied Separately) [2]					
Direction of Vehicle Acceleration	Seat (200 lb per)	Cargo Equipment (items that can get into cockpit) [6]			Equipment Mounted in Aft Equipment Compartment
Up	20		16		8
Down	10		8		4
Lateral	20		16		8
Forward	10		8		4
Aft	10		16		8
CH-47D/F Aircraft Crash Test Levels (g's) [3]					
Direction of Vehicle Acceleration	Applied Separately				
Up	-				
Down	8				
Lateral	8				
Forward	8				
Aft	-				
UH-1H Aircraft Crash Test Levels (g's) [4]					
Direction of Vehicle Acceleration	Applied Separately				
Up	8				
Down	4				
Lateral	±8				
Forward	8				
Aft	-				
UH/HH/MH-60A/L/M Aircraft Crash Test Levels (g's) [5]					
Direction of Vehicle Acceleration	Applied Separately	Applied Simultaneously [6]			External [6] (in any combination)
Up	20	10	20	10	6
Down	10	5	10	5	3
Lateral	±18	±9	±9	±18	3 (in) / 6 (out)
Forward	20	20	10	10	6
Aft	20	20	10	10	-

[1] See Design Criteria Report, Report No. 77-Y-8001-3 paragraph 6.1, reference b.

[2] See System Specification, Specification No. 406-947-500B paragraph 6.1, reference c.

[3] See reference Structural Design Criteria, Document No. 145-SS-603 paragraph 6.1, reference d.

[4] See reference System Specification, Contract DAAJ01-74-C-0175 paragraph 6.1, reference e.

[5] See reference Aircraft Specification, Document No. SES-700700 paragraph 6.1, reference f.

[6] Apply the worst case combination of test levels simultaneously. The requirement to test in different directions simultaneously can be accomplished through angled fixtures.

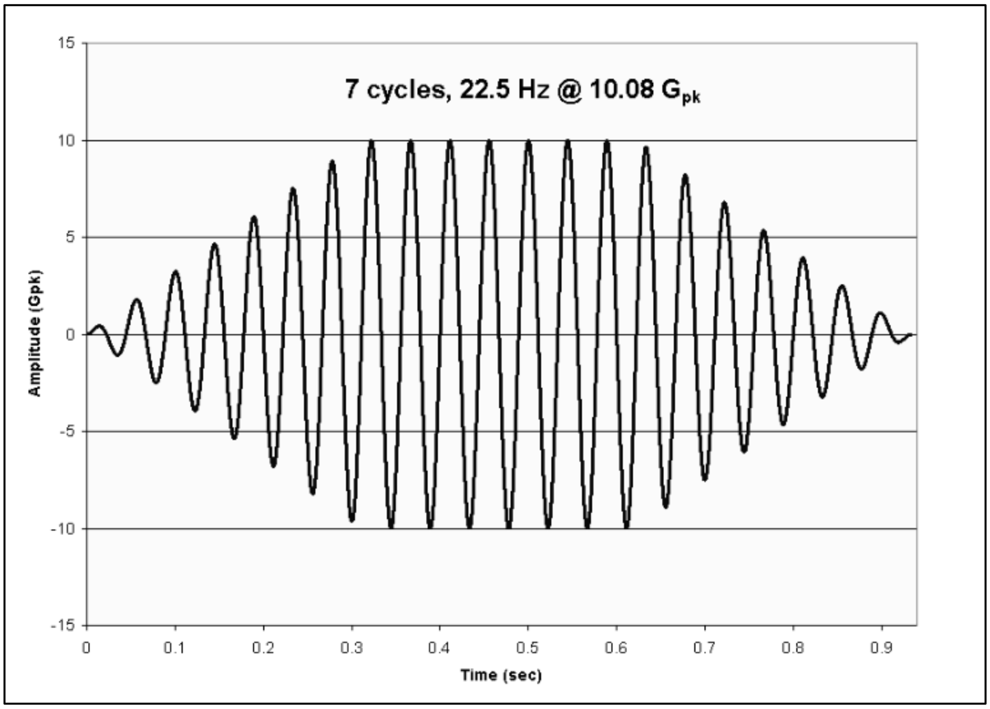

Figure 513.8-1. Example sine burst test specification for strength testing (from NASA-HDBK-7008).

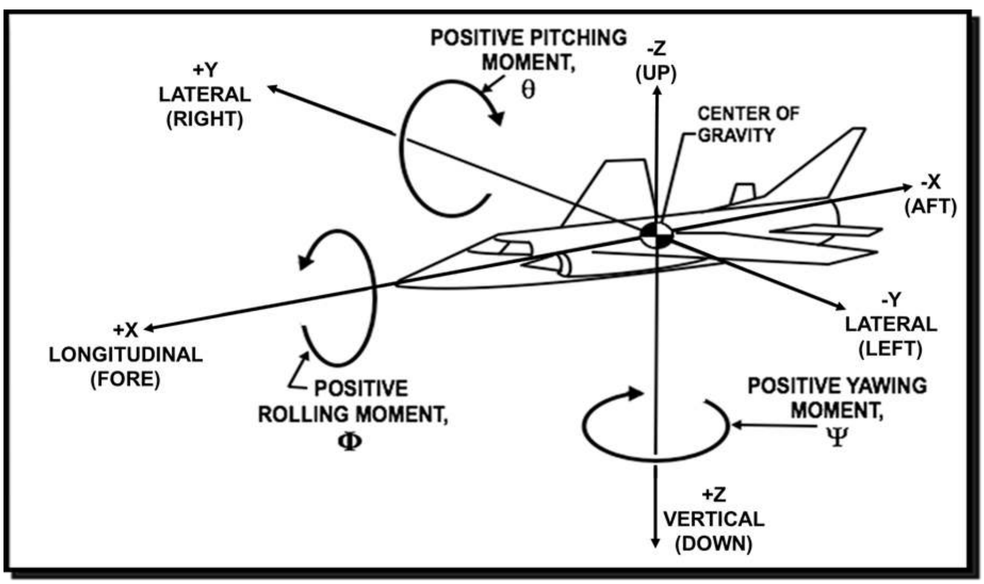

Figure 513.8-2. Typical directions of vehicle acceleration (right hand rule).

2.3.3 Test Levels and Conditions - Fighter and Attack Aircraft.

The test levels as determined from Tables 513.8-I and 513.8-II are based on accelerations at the center of gravity (CG) of the platform. For fighter and attack aircraft, the test levels, must be increased for materiel that is located away from the vehicle CG to account for loads induced by roll, pitch, and yaw during maneuvers. When criteria are developed for specific aircraft, maneuver cases are considered and the resulting additional angular accelerations may add or subtract effects from the linear acceleration effects. When the following relationships (a-f) are used, it must be assumed that the load factors always add. Thus absolute values are used in the equations. Add the load factors derived below to the Operational Test (Procedure II) levels of Table 513.8-II. Multiply the load factors derived below by 1.5 and add to the Structural Test (Procedure I) levels of Table 513.8-I. Do not add these values to the Crash Hazard Acceleration Test (Procedure III) levels of Tables 513.8-III and 513.8-IV.

a. Roll maneuver, up and down test direction. The additional load factor (ΔN_Z) induced by roll, is computed as follows:

$$\Delta N_Z = (z/g)\,(d\,\phi/d\,t)^2 + (y/g)\,d\,^2\phi/d\,t^2$$

b. Roll maneuver, lateral left and lateral right directions. The additional load factor (ΔN_Y) induced by roll, is computed as follows:

$$\Delta N_Y = (y/g)\,(d\,\phi/d\,t)^2 + (z/g)\,d\,^2\phi/d\,t^2$$

c. Pitch maneuver, up and down test directions. The additional load factor (ΔN_Z) induced by pitch change, is computed as follows:

$$\Delta N_Z = (z/g)\,(d\,\theta/d\,t)^2 + (x/g)\,d\,^2\theta/d\,t^2$$

d. Pitch maneuver, fore and aft test directions. The additional load factor (ΔN_X) induced by pitch change, is computed as follows:

$$\Delta N_X = (x/g)\,(d\,\theta/d\,t)^2 + (z/g)\,d\,^2\theta d\,t^2$$

e. Yaw maneuver, lateral left and right test directions. The additional load factor (ΔN_Y) induced by yaw, is computed as follows:

$$\Delta N_Y = (y/g)\,(d\,\psi/d\,t)^2 + (x/g)\,d\,^2\psi/d\,t^2$$

f. Yaw maneuver, fore and aft test directions. The additional load factor (ΔN_X) induced by yaw change, is computed as follows:

$$\Delta N_x = (x/g)\,(d\,\psi/d\,t)^2 + (y/g)\,d\,^2\psi/d\,t^2$$

Where:

x = fore and aft distance of materiel from the aircraft CG, m (in.)

y = lateral distance of materiel from the aircraft CG, m (in.)

z = vertical distance of materiel from the aircraft CG, m (in.)

g = acceleration of gravity, 9.81 m/sec^2 (386 in/sec^2)

ϕ = angle of rotation about the X axis (roll), rad

$d\,\phi/d\,t$ = maximum roll velocity in rad/sec (if unknown use 5 rad/sec)

$d\,^2\phi/d\,t^2$ = maximum roll acceleration in rad/sec^2 (if unknown use 20 rad/sec^2)

θ = angle of rotation about the Y axis (pitch), rad

$d\,\theta/d\,t$ = maximum pitch velocity in rad/sec (if unknown use 2.5 rad/sec)

$d\,^2\theta/d\,t^2$ = maximum pitch acceleration in rad/sec^2 (if unknown use 5 rad/sec^2)

ψ = angle of rotation about the Z axis (yaw), rad

$d\,\psi/d\,t$ = maximum yaw velocity in rad/sec (if unknown use 4 rad/sec)

$d\,^2\psi/d\,t^2$ = maximum yaw acceleration in rad/sec^2 (if unknown use 3 rad/sec^2)

2.4 Special Considerations.

a. Sway space measurements. If a piece of materiel is mounted on vibration isolators or shock mounts, perform the tests with the materiel mounted on the isolators/mounts. Measure the deflections of the isolators/mounts while the test item is exposed to the test accelerations. These data are needed to indicate potential interference with adjacent materiel, (i.e., define sway space requirements).

b. Acceleration simulation. Careful assessment of the function and characteristics of the test item has to be made in selecting the apparatus on which the acceleration tests are to be performed due to the differences in the manner in which acceleration loads are produced. There are two types of apparatus that are commonly used: the centrifuge and a track/rocket-powered sled combination.

c. Centrifuge. The centrifuge generates acceleration loads by rotation about a fixed axis. The direction of acceleration is always radially toward the center of rotation of the centrifuge, whereas the direction of the load induced by acceleration is always radially away from the axis of rotation. When mounted directly on the test arm, the test item experiences both rotational and translational motion. Ensure the centrifuge or turn table is properly balanced. The direction of the acceleration and the load induced is constant with respect to the test item for a given rotational speed, but the test item rotates 360 degrees for each revolution of the arm. Certain centrifuges have counter-rotating fixtures mounted on the test arm to correct for rotation of the test item. With this arrangement, the test item maintains a fixed direction with respect to space, but the direction of the acceleration and the induced load rotates 360 degrees around the test item for each revolution of the arm. Another characteristic is that the acceleration and induced load are in direct proportion to the distance from the center of rotation. This necessitates the selection of a centrifuge of adequate size so that the portions of the test item nearest to and furthest from the center of rotation are subjected to not less than 90 percent or more than 110 percent, respectively, of the specified test level. Further information regarding centrifuge testing may be found in paragraph 6.1, reference g.

d. Track/rocket-powered sled. The track/rocket-powered sled test arrangement generates linear acceleration in the direction of the sled acceleration. The test item mounted on the sled is uniformly subjected to the same acceleration level that the sled experiences. The acceleration test level and the time duration at the test level is dependent upon the length of the track, the power of the rocket, and the rocket charge. The sled track generally will produce a significant vibration environment due to track roughness. Typically this vibration is significantly more severe than the normal in-service use environment. Careful attention to the attachment design may be needed to isolate the test item from this vibration environment. In performing Procedure II tests, the support equipment necessary to operate the test item is mounted on the sled and traverses the track with the test item. This requires the use of self-contained power units and a remote control system to operate the test item while traversing the track. Telemetering or ruggedized instrumentation is required to measure the performance of the test item while it is exposed to the test load. Further information regarding rocket sled testing may be found in paragraph 6.1, reference h.

e. Sine burst testing. This method allows strength testing to be conveniently performed as part of a planned dynamic test sequence. Test schedule efficiency is improved because the test item can remain installed on the shaker table after a vibration test eliminating tear down, transport, and setup times at another facility. Note, it is important that all parties involved fully understand the risks and limitations of this approach. Possible test item damage may be caused by: shaker displacement limitations; open loop shaker control; and depending upon the level of test item assembly there may be unexpected amplification of component resonances in the hardware. Further information regarding this method may found in paragraph 6.1, reference i.

3. INFORMATION REQUIRED.

3.1 Pretest.

The following information is required to conduct acceleration tests adequately.

a. General. Information listed in Part One, paragraphs 5.7 and 5.9; and Part One, Annex A, Task 405 of this Standard.

b. Specific to this test Method.

(1) Vector orientation of test item with respect to the fixture.

(2) Vector orientation of fixture with respect to direction of acceleration.

(3) Photos of the test item and test setup before the tests.

(4) Center of gravity of the test item.

c. Tailoring. Necessary variations in the basic test procedures to accommodate LCEP requirements and facility limitations.

3.2 During Test.

Collect the following information during conduct of the test:

a. General. Information listed in Part One, paragraph 5.10; and in Part One, Annex A, Tasks 405 and 406 of this Standard.

b. Specific to this Method.

(1) Information related to failure criteria for test materiel under acceleration for the selected procedure or procedures. Pay close attention to any test item instrumentation and the manner in which the information is received from the sensors. For example, the acquisition of sensor signals from a test item on a centrifuge must consider either the way of bringing the sensor signals out through the centrifuge, a way of telemetering the sensor signals, or the effects of the acceleration on a recorder mounted on the centrifuge near the sensor for obtaining the sensor signals.

(2) Photos of the test item and test setup during tests.

(3) Record the time history of pertinent test data using a data recording device.

3.3 Post-Test.

The following post test data shall be included in the test report.

a. General. Information listed in Part One, paragraph 5.13; and in Part One, Annex A, Task 406 of this Standard.

b. Specific to this Method.

(1) Vector orientation of test item with respect to the fixture.

(2) Vector orientation of fixture with respect to direction of acceleration.

(3) Photos of the test item after the tests.

(4) Record of time history pertinent test data.

(5) Any deviations from the original test plan.

4. TEST PROCESS.

4.1 Test Facility.

The required apparatus consists of either a centrifuge of adequate size or a track/rocket-powered sled test arrangement. Recommend a centrifuge for all Procedure I (Structural Test), Procedure III (Crash Hazard Acceleration Test), and most of Procedure II (Operational Test) evaluations. Use a track/rocket-powered sled test arrangement for Procedure II evaluations when strictly linear accelerations are required. In general, acceleration tests will not be instrumented. If there is need for test apparatus or test fixture/test item instrumentation, follow practices and procedures outlined in paragraph 6.1, reference j. Verification of the correct input acceleration to the test item will be according to procedures established at the test facility.

4.2 Controls.

4.2.1 Calibrations.

Ensure any acceleration measurement for test verification has been made by instrumentation properly calibrated to the amplitude and frequency ranges of measurement.

4.2.2 Tolerances.

Maintain the acceleration level between 90 percent and 110 percent of the specified level over the full dimensions of the test item.

4.3 Test Interruption.

Test interruptions can result from two or more situations, one being from failure or malfunction of test chambers or associated test laboratory equipment. The second type of test interruption results from failure or malfunction of the test item itself during required or optional performance checks.

4.3.1 Interruption Due To Laboratory Equipment Malfunction.

a. General. See Part One, paragraph 5.11, of this Standard.

b. Specific to this Method.

(1) If an unscheduled interruption occurs while the test item is at a specified test level, restart and run the complete test. If interruptions result in several new starts, evaluate the test item for fatigue damage. (Each application of acceleration is a single loading cycle. Duration of a loading cycle does not influence the severity of the test.)

(2) If the test item is subjected to acceleration loads in excess of the level specified for the test, stop the test, inspect the test item and perform a functional test. Based on the inspection and functional test, make an engineering decision as to whether to resume testing with the same test item or with a new test item.

4.3.2 Interruption Due To Test Item Operation Failure.

Failure of the test item(s) to function as required during mandatory or optional performance checks during testing presents a situation with several possible options.

a. The preferable option is to replace the test item with a "new" one and restart from Step 1.

b. A second option is to replace / repair the failed or non-functioning component or assembly with one that functions as intended, and restart the entire test from Step 1.

> **NOTE**: When evaluating failure interruptions, consider prior testing on the same test item and consequences of such.

4.4 Test Setup.

See Part One, paragraph 5.8.

4.5 Test Execution.

The following steps provide the basis for collecting necessary information concerning the test item in a constant acceleration environment.

4.5.1 Preparation for Test.

4.5.1.1 Pretest Standard Ambient Checkout.

All items require a pretest standard ambient checkout to provide baseline data and additional inspections and performance checks during and after tests. Conduct inspections as follows:

Step 1 Examine the test item for physical defects, etc., and record findings.

Step 2 Prepare the test item for test, in its operating configuration if required, as specified in the test plan.

Step 3 Obtain sufficient dimensional measurements of the test item to provide a reference guide for the evaluation of physical damage that may be induced during the tests.

Step 4 Examine the test item/fixture/centrifuge/sled combination for compliance with the test item and test plan requirements.

Step 5 If applicable, conduct an operational checkout in accordance with the test plan, and document the results. If the test item operates satisfactorily, proceed to paragraph 4.5.2 or 4.5.3 as appropriate. If not, resolve the problems and repeat this Step.

4.5.1.2 Mounting of the Test Item.

Configure the test item for service application. Mount the test item on the test apparatus using the hardware that is normally used to mount the materiel in its service installation.

a. Centrifuge mounting.

Step 1 Determine the mounting location for the test item by measurement from the center of rotation of the centrifuge to the location on the centrifuge arm that will provide the g level established for the test. Mount the test item so that its center of gravity is at the location on the arm determined for the test load factor (g level). Calculate test levels as follows:

$$N_T = K\ r\ n^2$$

Where:

N_T = test load factor (load factor within the centrifuge plane of rotation)

K = 1.118×10^{-3}, r in meters ($K = 2.838 \times 10^{-5}$, r in inches)

r = radial distance in meters, (inches) from the center of rotation to the mounting location on centrifuge arm

n = angular velocity of centrifuge arm in revolutions per minute (rpm)

Step 2 Orient the test item on the centrifuge for the six test direction conventions as follows:

(a) Fore. Front or forward end of test item facing toward center of centrifuge.

(b) Aft. Reverse the test item 180 degrees from fore position.

(c) Up. Top of test item facing toward center of centrifuge.

(d) Down. Reverse item 180 degrees from up position.

(e) Lateral left. Left side of test item facing toward center of centrifuge.

(f) Lateral right. Right side of test item facing toward center of centrifuge.

Step 3 After the test item is properly oriented and mounted on the centrifuge, make measurements and calculations to ensure the end of the test item nearest to the center of the centrifuge will be subjected to no less than 90 percent of the g level established for the test. If the g level is found to be less than 90 percent of the established g level, either mount the test item further out on the centrifuge arm and adjust the rotational speed accordingly, or use a larger centrifuge to ensure the end of the test item nearest to the center of the centrifuge is subjected to at least 90 percent of the established g level. However, do not subject the opposite end of the test item (the end farthest from the center of the centrifuge) to over 110 percent of the established g level. For large test items, consider exceptions for load gradients based on the existing availability of large centrifuges in commercial or government test facilities.

b. Track/rocket-powered-sled mounting. For track/rocket-powered sled mounting, mount the test item and associated test fixture or apparatus on the sled platform in accordance with the controlled acceleration direction of the sled. (Ensure the test fixture or apparatus has been designed to isolate sled vibrations from the test item.) Since the sled and test item experience the same g levels, only the orientation of the test item on the sled is critical. Orient the test item on the sled according to the acceleration directions shown on Figure 513.8-2 and the controlled acceleration direction of the sled for the six test directions.

c. Shaker mounting. Before starting a test, review pretest information in the test plan to determine test details (test item configuration(s), levels, durations, failure criteria, item operational requirements, instrumentation requirements, facility capability, fixture(s), etc.).

Step 1 Select appropriate vibration exciters and fixtures.

Step 2 Select appropriate data acquisition system (e.g., instrumentation, cables, signal conditioning, recording, analysis equipment).

Step 3 Operate vibration equipment without the test item installed to confirm proper operation.

Step 4 Ensure the data acquisition system functions as required.

4.5.2 Procedure I - Structural Test.

Step 1 With the test item installed as in paragraph 4.5.1.2, bring the centrifuge to the speed required to induce the specified g level in the test item as determined from paragraph 2.3 and Table 513.8-I for the particular test item orientation. Maintain this g level for at least one minute after the centrifuge rpm has stabilized.

Step 2 Stop the centrifuge and inspect the test item as specified in paragraph 4.5.1.1.

Step 3 Operationally test and inspect the test item as specified in paragraph 4.5.1.1. If the test item fails to operate as intended, see paragraph 5 for analysis of results, and follow the guidance in paragraph 4.3.2 for test item failure.

Step 4 Repeat this test procedure for the remaining five test directions noted in paragraph 4.5.1.2.a, Step 2.

Step 5 Upon completing the tests in the six test directions, remove the test item from the centrifuge and, if required, perform one final operational check and physical inspection. See paragraph 5 for analysis of results.

4.5.3 Procedure II - Operational Test.

4.5.3.1 Centrifuge.

Step 1 With the test item installed as in paragraph 4.5.1.2, operationally test and inspect the test item as specified in paragraph 4.5.1.1.

Step 2 With the test item operating, bring the centrifuge to the speed required to induce specified g level in the test item as determined from paragraph 2.3 and Table 513.8-II for the particular test item orientation. Maintain this g level for at least one minute after the centrifuge rpm has stabilized. Conduct an operational check and document the results. If the test item fails to operate as intended, follow the guidance in paragraph 4.3.2 for test item failure.

Step 3 Stop the centrifuge and operationally check and inspect the test item as specified in paragraph 4.5.1.1. If the test item fails to operate as intended, see paragraph 5 for analysis of results.

Step 4 Repeat Steps 1-3 for the five remaining orientations noted in paragraph 4.5.1.2.a, Step 2.

Step 5 Upon completing the tests in the six test directions, remove the test item from the centrifuge and, if required, perform one final operational check and physical inspection. See paragraph 5 for analysis of results.

4.5.3.2 Track/Rocket Powered Sled.

Step 1 With the test item installed as in paragraph 4.5.1.2, operationally test and inspect the test item as specified in paragraph 4.5.1.1.

Step 2 With the test item operating, accelerate the sled to the level required to induce the specified g level in the test item as determined from paragraph 2.3 and Table 513.8-II for the particular test item orientation. Conduct a performance check while the test item is subjected to the specified g level. Document the results.

Step 3 Evaluate test run parameters and determine if the required test acceleration was achieved.

Step 4 Repeat the test run as necessary to demonstrate acceptable performance of the test item while under required test acceleration. Document the test run parameters.

Step 5 Repeat this test procedure for the five remaining test directions noted in paragraph 4.5.1.2a, Step 2. Upon completing the tests in the six test directions, operationally check and inspect the test item according to paragraph 4.5.1.1. See paragraph 5 for analysis of results.

4.5.4 Procedure III - Crash Hazard Acceleration Test.

Step 1 With the test item installed as in paragraph 4.5.1.2, bring the centrifuge to the speed required to induce the specified g level in the test item as determined from paragraph 2.3 and Table 513.8-III or Table 513.8-IV for the particular test item orientation. Maintain this g level for at least one minute after the centrifuge rpm has stabilized.

Step 2 Stop the centrifuge and inspect the test item as specified in paragraph 4.5.1.1.

Step 3 Inspect the test item as specified in paragraph 4.5.1.1.

Step 4 Repeat this test procedure for the remaining five test directions noted in paragraph 4.5.1.2.a, Step 2.

Step 5 Upon completing the tests in the six test directions, inspect the test item as specified in paragraph 4.5.1.1. See paragraph 5 for analysis of results.

4.5.5 Procedure IV – Strength Test.

Step 1 Select the test conditions which are within the shaker displacement limits and mount the test item (or dynamic simulant item) on the vibration exciter. Use of a simulant may be desired to assess system drive signal magnitudes. Install accelerometers, force gages, and other instrumentation as required.

Step 2 If required; perform an operational check on the test item at standard ambient conditions. If the test item operates satisfactorily, proceed to Step 3. If not, resolve the problems and repeat this step.

Step 3 Subject the test item (or dynamic simulant) to the sine burst profile. The vibration control system will be in open loop control. Examine the data and adjust the parameters to achieve the required test level. If a dynamic simulant is used, then replace the simulant with the test item.

Step 4 Subject the test item in its operational configuration to the compensated sine burst waveform. It is often desirable to make an initial run at less than full level to ensure proper dynamic response and validate instrumentation functionality.

Step 5 Record necessary data.

Step 6 Examine the control acceleration time trace for conformance to the test profile. Perform a visual inspection of the test item. Conduct an operational check on the test item and record the performance data as required.

Step 7 Repeat Steps 4, 5, and 6 for the number of replications called out in the requirements document, or a minimum of three times for statistical confidence provided the integrity of the test configuration is preserved during the test.

Step 8 Remove the test item from the fixture/shaker and inspect the test item, mounting hardware, components, etc., for any signs of visual mechanical degradation that may have occurred during testing.

Step 9 If required, repeat Steps 1-8 for each excitation axis.

Step 10 Document the test series including the saving of all control and monitor digital time traces, and see paragraph 5.2.4 for analysis of results.

5. ANALYSIS OF RESULTS.

5.1 General.

Refer to the guidance in Part One, paragraphs 5.14 and 5.17; and to Part One, Annex A, Task 406.

5.2 Specific to This Method.

5.2.1 Structural Test.

A test is successful if the test item is undamaged and fully operational at test completion.

5.2.2 Operational Test.

A test is successful if the test item is fully operational at test accelerations, and is undamaged and fully operational at test completion.

5.2.3 Crash Hazard Acceleration Test.

A test is successful if the test item remains structurally attached to the mounts and no parts, pieces, or contents are detached from the item at test completion.

5.2.4 Strength Test.

A test is successful if the test item is undamaged and fully operational. Components shall remain structurally attached to the mounts and no parts, pieces, or contents are bent or detached from the item at test completion.

6. REFERENCE/RELATED DOCUMENTS.

6.1 Referenced Documents.

a. Westar Aerospace and Defense Group - To Verify or Modify the MIL-STD-810 Default Acceleration Crash Safety Test Levels As Applied to Our Army Fixed and Rotary Winged Aircraft (Tasking Number 18605), 3 Jan 2006.

b. Design Criteria Report, Report No. 77-Y-8001-3.

c. System Specification, Specification No. 406-947-500B.

d. Structural Design Criteria, Document No. 145-SS-603.

e. System Specification, Contract DAAJ01-74-C-0175.

f. Aircraft Specification, Document No. SES-700700.

g. International Test Operations Procedure (ITOP) 05-2-586A Sustained Acceleration (Centrifuge) Testing, 8 June 2017.

h. ITOP 05-1-029 Rocket Sled Testing, 18 September 2015.

i. NASA-HDBK-7008 Spacecraft Dynamic Environments Testing, Paragraph 5.4.1.3, 12 June 2014.

j. Handbook for Dynamic Data Acquisition and Analysis, IES-RP-DTE012.2, Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516; Institute of Environmental Sciences and Technology Website.

k. Westar Aerospace and Defense Group Memo - Are the MIL-STD-810F Acceleration Operational Test Levels per Table 513.5-II Too High for Army Aircraft Qualification Requirements? (Log Number 4542), 24 July 2002

6.2 Related Documents.

a. Junker, V.J., The Evolution of USAF Environmental Testing. October 1965; AFFDL TR 65-197; DTIC No. AD 625543.

b. Allied Environmental Conditions and Test Publication (AECTP) 400, Mechanical Environmental Tests (under STANAG 4370), Method 404.

c. Egbert, Herbert W. "The History and Rationale of MIL-STD-810 (Edition 2)", January 2010, Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516.

d. Rogers J.D. et.al., VIBRAFUGE - Combined Vibration and Centrifuge Testing, 60th Shock and Vibration Symposium Proceedings, SAVIAC, 1989, volume III, page 63. Shock & Vibration Information Analysis Center (SAVIAC), PO Box 165, 1104 Arvon Road, Arvonia, VA 23004.

(Copies of Department of Defense Specifications, Standards, and Handbooks, and International Standardization Agreements are available online at https://assist.dla.mil.

Requests for other defense-related technical publications may be directed to the Defense Technical Information Center (DTIC), ATTN: DTIC-BR, Suite 0944, 8725 John J. Kingman Road, Fort Belvoir VA 22060-6218, 1-800-225-3842 (Assistance--selection 3, option 2), http://www.dtic.mil/dtic/; and the National Technical Information Service (NTIS), Springfield VA 22161, 1-800-553-NTIS (6847), http://www.ntis.gov/.

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METHOD 513.8, ANNEX A

TEST CONSIDERATIONS

1. TEST ITEM MOUNTING FIXTURE.

1.1 Fixture Design Considerations.

An installation design in which centrifugal force tends to hold the test item against the machine or fixture as shown in Figures 513.8A-1 and 513.8A-2 is generally preferred for unusually severe acceleration conditions, since this type of installation tends to minimize the possibility of accidental loss of the test item during a test. In this case, a compressive stress at the test item attachment location results from the normal or centripetal acceleration. A centrifuge equipped with an adjustable mounting table has definite advantages over a machine with a fixed mounting surface as being adjustable means greater versatility in the test installation. For example, an adjustable mounting table that may be rotated relative to the axis of the centrifuge arm might allow a test installation of the type referred to above or allow a choice of more than one test item axis for exposure to the acceleration vector without detaching the test item to re-orientate it for each axis tested. Difficulties in such operations as installation, checkout, servicing, and removal of the test item can be reduced by using a mounting table that allows a change in position relative to the centrifuge arm.

The testing of small items, or items that are difficult to set up, may be expedited by using a fixture that allows exposure of each axis to the acceleration vector without removal of the test item from the fixture. In this procedure, the fixture (with the test item attached to it) is re-oriented. One of the simpler fixtures of this type holds the test item at a central location so that any number of fixture faces may be attached to the centrifuge mounting table depending upon the item orientation required. Installations of this type are usually bolted to the centrifuge. At centrifuge sites where numerous tests requiring re-orientation of the test object are conducted, fixture versatility means reduced costs in test programs and less time to complete tests.

The decision in favor of a particular fixture design may be affected by such considerations as:

a. The scope of the test program.

b. The complexity of test requirements.

c. Physical characteristics of the test item.

d. Centrifuge design.

The economics of conducting a centrifuge test are often primary considerations. If the test program is a large one requiring a test to be duplicated for a number of like test items, an elaborate fixture design that minimizes the installation and test time for each test item may be required. The design and cost of the fixture, in this case, might be justified by a reduction in the cost of the program such that the cost of fixture design and fabrication is a fraction of the total amount saved. Conversely, a small number of tests might be conducted more economically by using a simple installation in which the test item is unfastened from the centrifuge and re-orientated for each part of a test.

Knowledge of the ability of supporting bracketry to carry the required loads is an important factor in the preparation for a centrifuge test. A detailed analysis may not be necessary, if a previously used mounting bracket is to be exposed to loads known to be less severe than those for which it was designed; however, a preliminary design investigation, including a force and stress analysis, usually is required in conjunction with a new test installation. Basic forces imposed on the test item by centrifuge accelerations are shown in Figures 513.8A-l, 513.8A-2, and 513.8A-3.

Free-body diagrams showing the forces at critical locations under various load conditions are commonly used in making the force analysis. After the forces have been identified as to point of application, direction, and magnitude, the stress analysis is undertaken. The analysis may require consideration of as many as four separate loading cases: axial force, transverse force (shear), bending, and torsion. In a bracket under complex loading conditions, it is possible that more than one of these conditions will exist. Loading conditions, that appear to be relatively simple, are sometimes required to be broken down into idealized conditions. After each loading condition has been analyzed to determine stresses and deflections, the results are combined to determine total strength and deflection characteristics.

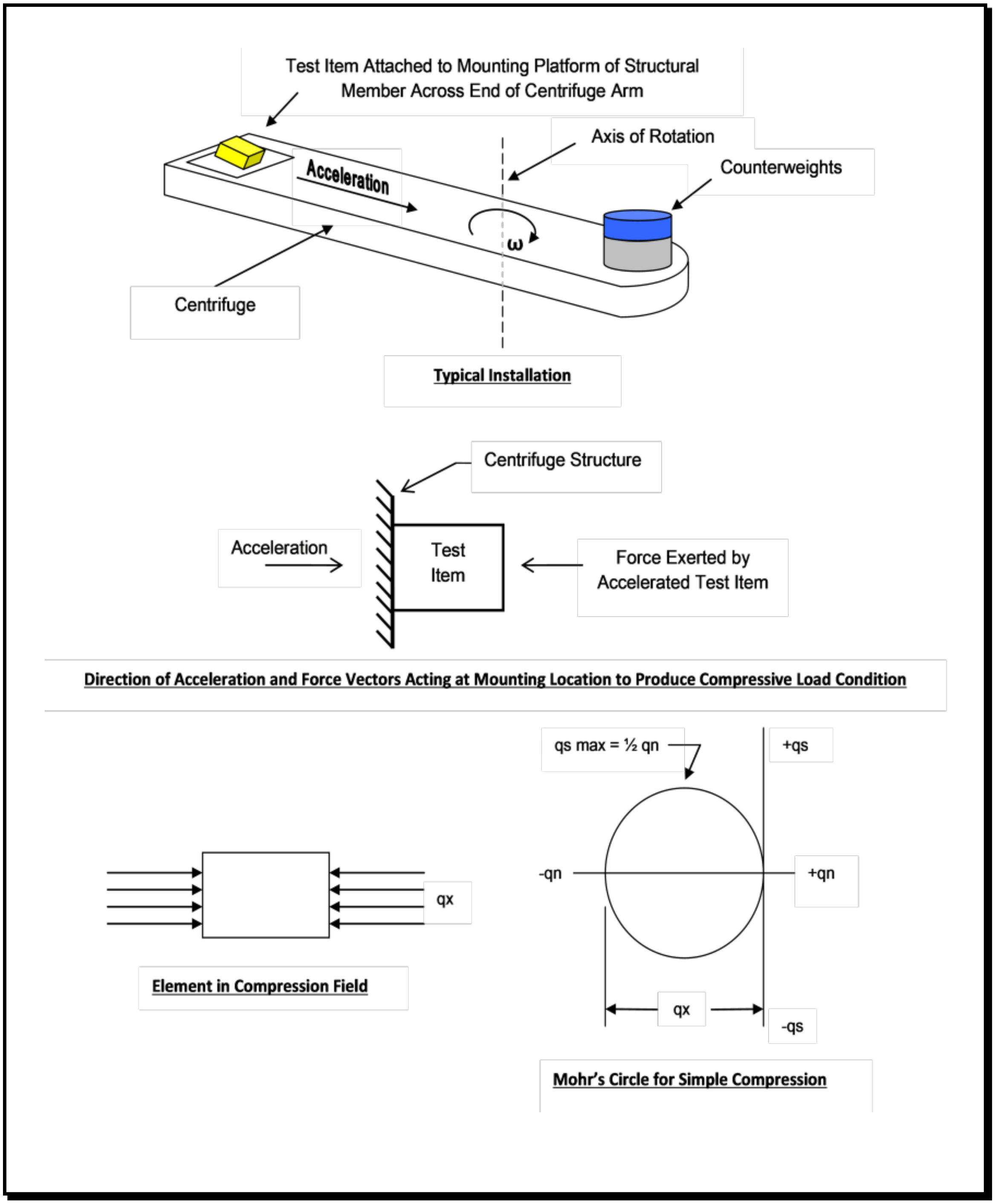


Figure 513.8A-1. Basic centrifuge test installation resulting in compressive load conditions.

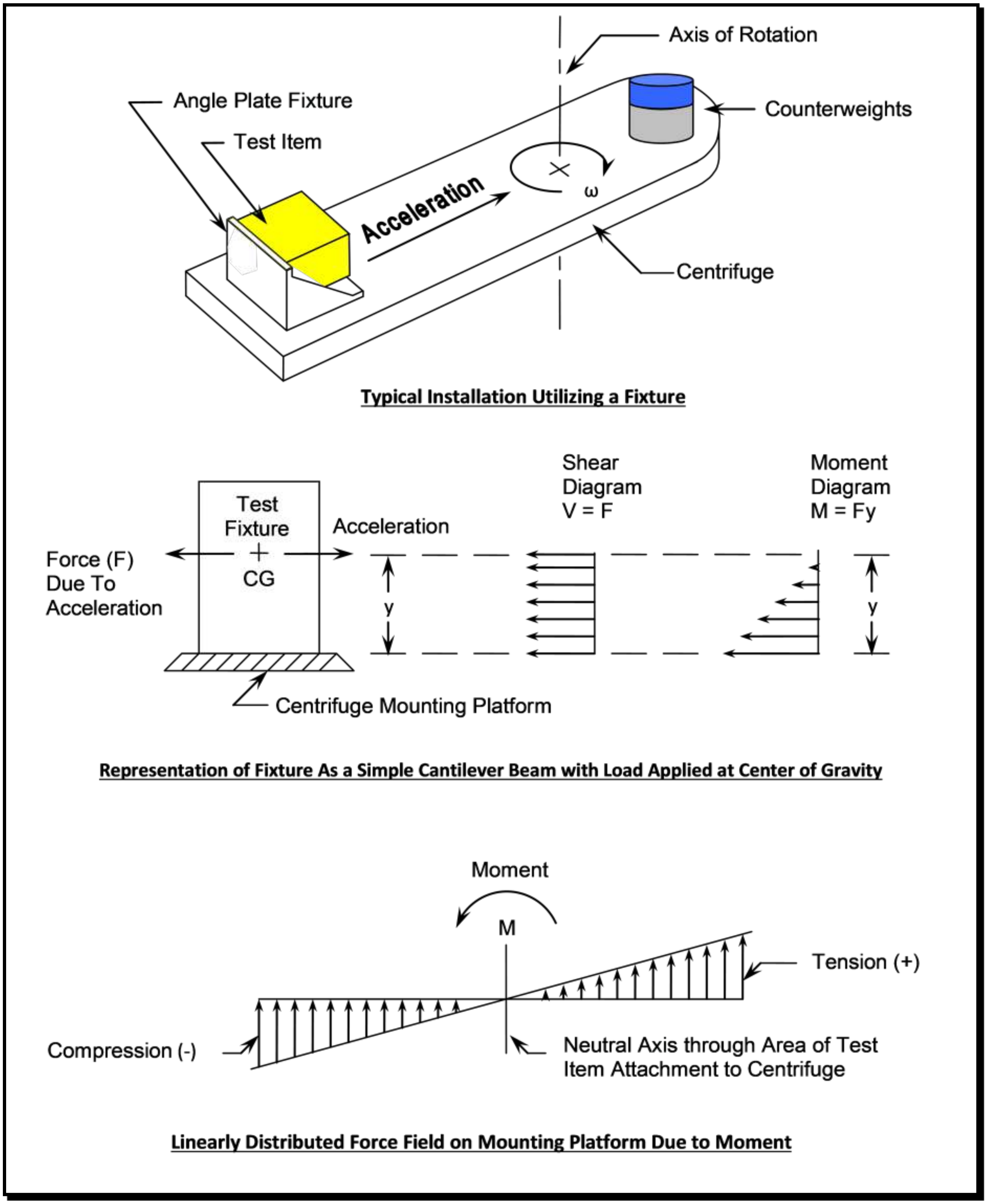
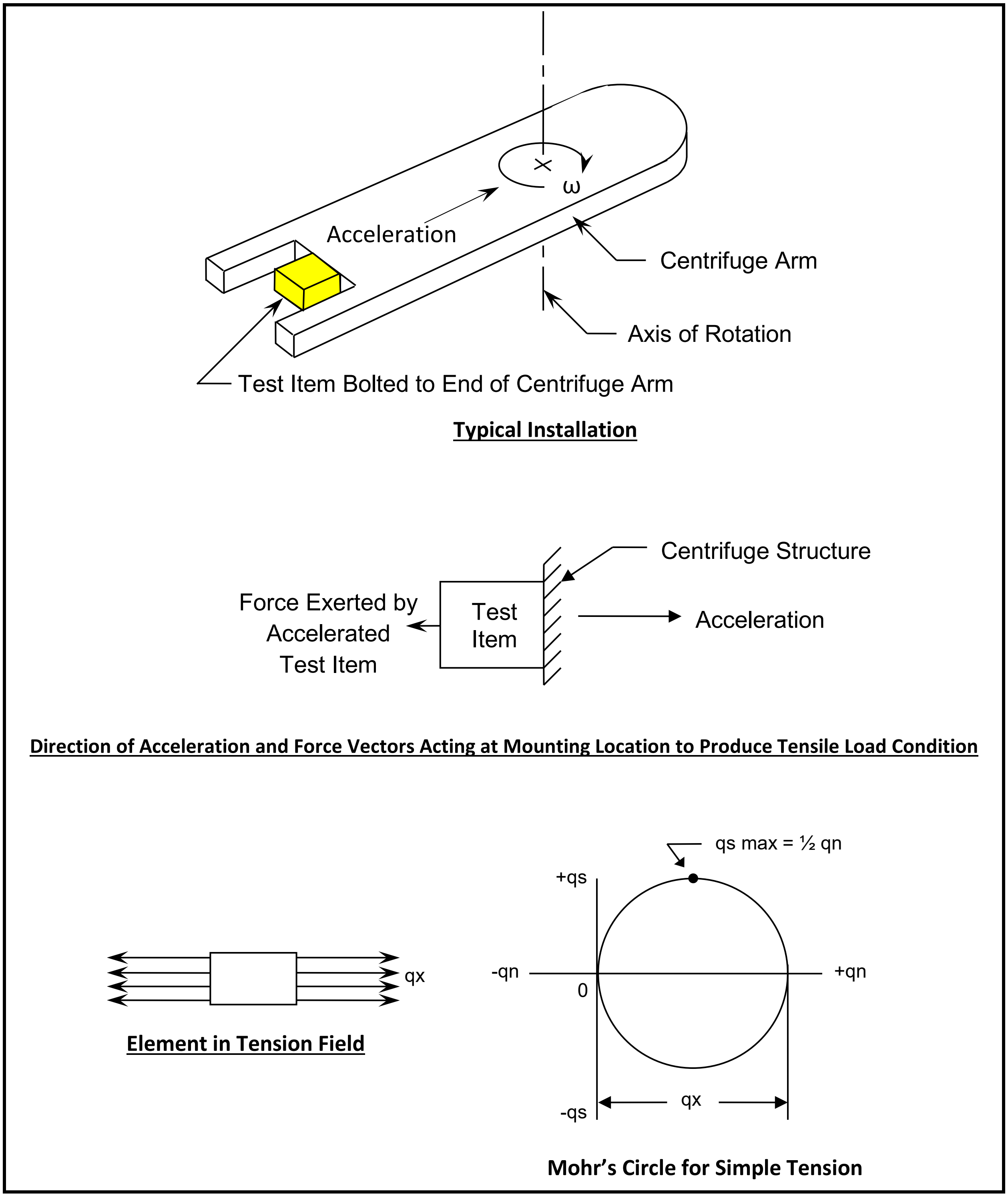


Figure 513.8A-2. A typical centrifuge test installation requiring consideration of moment effects in installation design.



513.8A-3. Basic centrifuge test installation resulting in tensile load conditions.

Occasionally, the design of a centrifuge test installation may require that the bracketry weight be kept at a minimum so that the total installation load does not exceed the centrifuge load limits. This, as in other areas of structural design, may require a careful investigation of various combinations of stress at critical locations. The complexity of the load conditions is dependent upon the centrifuge test requirements as well as the configuration of the test item and the bracketry by which the test item is attached to the centrifuge. Test conditions and the installation may be such that only simple bracketry loading involving shear, tension, or compression requires consideration, or the test may be such that various loading conditions exist with combined stresses that vary with time. An analysis of the more complex loading conditions may require investigation of the state of stress and strain, and the deflection due to distributed forces or force fields. The use of experimental, as well as analytical, analysis tools may be necessary to obtain an analysis in sufficient detail. Standard strength-of-materials references are adequate for most of the structural design required in conjunction with centrifuge testing. Some typical centrifuge test item installations and the basic bracketry load and stress considerations are shown in Figures 513.8A-l, 513.8A-2, and 513.8A-3.

1.2 Fixture Materials and Construction.

In selecting the material for a fixture, two important factors to be considered are the stress to which the fixture will be subjected, and the weight the centrifuge arm can support. Other factors that should be taken into account are machinability and fabrication qualities. The material giving the lowest cost, yet having the properties needed, generally is considered the best engineering material. However, test schedule and material availability influence the choice of materials to be used. Aluminum and magnesium combining lightness with good mechanical properties to give a high strength-to-weight ratio are frequently used for centrifuge test fixtures. Both metals are available in a variety of forms including standard sheet, plate, bar stock, and miscellaneous shapes, and both have generally desirable fabrication qualities. Most of the fusion and mechanical fastening methods common to the metal working trades may be used in the fabrication of fixtures, however, the designer should be aware of the characteristics of each material under his design conditions. Inserts may be used to reinforce the fixture base metal. In bolted connections, they increase the resistance to severe loading conditions and/or to thread wear due to repeated use of the fixture. A bolted fixture design may be found desirable because of the versatility of this fabrication method in new fixtures, as well as in the adaptation of fixtures previously used for other tests. The fixture may either bolt directly to the centrifuge platform or, if necessary, to an adapter plate that, in turn, is bolted to the centrifuge arm.

1.3 General Considerations in Centrifuge Testing.

Although testing by means of the centrifuge appears to be simple when compared with other types of testing, the test engineer may encounter numerous issues that vary in magnitude depending upon the complexity of the test. Typical issues encountered are those associated with the generation of required test conditions, data acquisition, test item servicing and handling, and miscellaneous support of the type supplied at the test site.

The generation of acceleration conditions other than those required at the test item location may be objectionable. An acceleration gradient along the axis of the centrifuge arm and a tangential acceleration exist at the test item location in varying degrees of intensity during the operation of a centrifuge.

Centrifugally-produced forces are not uniform along a test specimen on a centrifuge because of the proportionality of acceleration to the radius. The normal acceleration (along the length of the centrifuge arm) varies directly with the radius and by the square of the angular velocity ($a_n = r\omega^2$). The effect of the incremental variation of acceleration along the radius of a centrifuge arm may be undesirable if a test item is required to be subjected to an acceleration value within specified tolerances at more than one location, and test item dimensions along the centrifuge arm are such that the difference in acceleration between these locations is excessive. The importance of a centrifuge with a large radius is appreciated in such a situation, since the incremental variation of acceleration over the test item is less if the item was installed at the end of a centrifuge arm of greater length.

In tests requiring acceleration values to be maintained within close tolerances on a large object, it may be desirable to adjust the centrifuge rotational speed so the required acceleration is obtained at the location (radius of gyration) of a critical test item component.

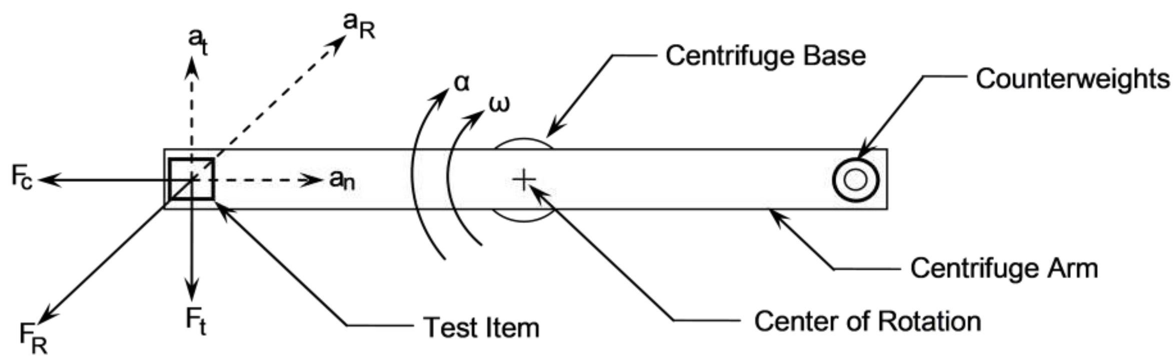
The effect of tangential acceleration ($a_t = r\alpha$) on the resultant acceleration vector should not be overlooked. This acceleration occurs in a direction perpendicular to that of the normal acceleration, and may be large enough to cause a considerable change in direction and magnitude of the resultant acceleration vector. Because of centrifuge design and power requirements, the tangential acceleration usually encountered on a large centrifuge is relatively low. However, the tangential acceleration generated by changes in rotational speed of smaller centrifuges may become significantly large. If test specifications require a rapid g level ramp rate within the limits attainable on a centrifuge, it may be necessary to provide a means of accounting for large tangential acceleration values at the test item location. There have been designs that allow the test item to be rotated relative to the centrifuge arm in such a way that the resultant of the normal and tangential acceleration vectors remains orientated along the desired axis of the test object during periods when a change in centrifuge rotational speed occurs. Figure 513.8A-4 depicts the forces due to rotation and change in rotational speed of the centrifuge.

2. FAILURE DETECTION PROBLEMS.

During a centrifuge test, the detection and analysis of the cause of failure may be difficult. For example, during a centrifuge test, an electronic circuit in a test item might fail due to a capacitor short. This failure might have occurred regardless of the test, or might have been a direct result of the test. Other possibilities exist and a conclusion that the capacitor failed as a result of the test is extremely uncertain without additional evidence. Careful technical consideration must be given to the cause and effect relationship of each failure to prevent erroneous conclusions and unnecessary redesign efforts. There is no definite procedure for failure investigation or troubleshooting; except that drawings, system specification documents, operating instructions, and good engineering practices should be used. Failure may be classified as intermittent, catastrophic, or fatigue. An intermittent failure is one that occurs during the test, but disappears when the test item returns to normal operation after the causative influence is removed. Catastrophic or fatigue failure is one that results in the structural failure of a component of the test item, and can be detected by inspection of instrumentation after the test is concluded.

3. ACCELERATION AND FORCE CALCULATION.

Figure 513.8A-4 depicts the forces due to rotation and change in rotational speed of the centrifuge.



Acceleration $$a_R = \sqrt{a_t^2 + a_n^2}$$	a_R = resultant acceleration where normal and tangential acceleration exist a_t = $r\alpha$, tangential acceleration a_n = $r\omega^2$, normal acceleration α = change in centrifuge rotational acceleration (radians/second squared) ω = centrifuge rotational velocity (radians/second)
Force $$F_R = \sqrt{F_t^2 + F_c^2}$$	F_R = resultant force F_t = ma_t , force due to tangential acceleration F_c = ma_n , centrifugal force due to normal acceleration m = mass of the test item
General Expression* $$g's = \frac{\pi^2 N^2 r}{900G}$$ * Derived from equation for normal acceleration, $a_n = r\omega^2$	g = acceleration as a number of gravity units G = gravitational unit of acceleration (9.81 meter/sec^2 (32.2 ft/sec^2)) π = 3.14159 N = revolutions per minute r = radius of gyration (feet or inches)
Centimeter Units $g's = 0.1118 \times 10^{-4}\, r\, N^2$	Inch Units $g's = 0.2838 \times 10^{-4}\, r\, N^2$
Meter Units $g's = 0.1118 \times 10^{-2}\, r\, N^2$	Feet Units $g's = 0.3406 \times 10^{-3}\, r\, N^2$

Figure 513.8A-4. Basic forces imposed on test item due to accelerations produced by centrifuge.