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PYROTECHNIC SHOCK AT THE ORBITER/EXTERNAL TANK FORWARD ATTACHMENT

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ABSTRACT

During the initial certification test of the forward structural attachment of the Space Shuttle Orbiter to the External Tank, pyrotechnic shock from actuation of the separation device resulted in structural failure of the thermal protection tiles surrounding the attachment. Because of the high shock associated with the separation bolt, the development of alternative low-shock separation designs was initiated. Two concepts that incorporate a 5.08-centimeter (2-inch) frangible nut as the release device have been developed and tested at the NASA Lyndon B. Johnson Space Center.

INTRODUCTION

Pyrotechnic-actuated devices are used to release the External Tank (ET) (fig. 1) during separation of the Space Shuttle Orbiter from the ET. These devices must meet the system design requirements to sustain the flight loads and to separate cleanly at the moment of release. At the forward structural attachment, the device must also meet close-tolerance aerothermodynamic smoothness requirements for the Orbiter outer mold line following separation.

During the initial certification test of the forward attachment, pyrotechnic shock from actuation of the separation device resulted in structural failure of the thermal protection tiles surrounding the attachment. The test data also indicated that shock levels transmitted to the forward avionics bay of the Orbiter would exceed the qualification levels of some of the equipment.

To meet these diverse design requirements and to quickly obtain test data on alternative low-shock separation designs at the NASA Lyndon B. Johnson Space Center (JSC) and at the prime contractor facility, two designs incorporating a 5.08-centimeter (2-inch) frangible nut were investigated. The 5.08-centimeter (2-inch) frangible nut was chosen for this application because (1) it could withstand the structural flight loads at the Orbiter forward attachment, (2) the pyrotechnic shock from this device would be low compared to that of the baseline separation bolt design, and (3) hardware to perform development tests was readily available. These designs were investigated as possible substitutes for the baseline separation bolt in the event that baseline modifications were not satisfactory.

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DESIGN REQUIREMENTS

The separation system design requirements can be divided into two general categories: structural and mechanical. The separation hardware is the primary structural load path between the Orbiter and the ET; hence, the hardware must satisfy the overall structural design requirements of the spacecraft for the prelaunch, launch, and boost environments. For separation, the system acts as a mechanical device and must satisfy the design requirements to ensure a safe separation.

The mechanical design requirements for the Orbiter/ET separation are

1. To provide release of the Orbiter from the ET for normal and abort separation
2. To preclude degradation of Orbiter functional systems after separation
3. To satisfy aerothermal smoothness criteria after separation
4. To separate without releasing debris
5. To incorporate acceptable assembly and mating procedures

To satisfy these design requirements and to develop a separation system with low-shock characteristics, the 5.08-centimeter (2-inch) frangible nut was chosen. This nut was selected because it has the strength to withstand the structural flight loads at the forward attachment, data indicate that pyrotechnic shock would be low compared to that of the baseline design, and the hardware is readily available to perform development tests.

Selection of a design to meet specific requirements generally involves some compromises. For example, the baseline shear-bolt design meets the requirements for a clean separation and a smooth outer mold line exceedingly well with a relatively simple device. The piston ejects the severed stud with a high force so that the potential for hangup is virtually nonexistent. The stud has to move only about 2.54 centimeters (1 inch) to clear the Orbiter outer mold line and, even under side-load conditions for a separation during an abort, separation is positive. Unfortunately, the pyrotechnic shock associated with this device damages tiles adjacent to the attach point and may adversely affect the operation of avionics equipment located nearby.

The low-shock devices that have been investigated by JSC and the prime contractor have a potential to hang up under the side-load conditions associated with an abort separation. This problem has become a significant challenge in developing a low-shock system and is receiving emphasis in an ongoing design and test effort.

BASELINE SEPARATION SYSTEM

The major components for separation of the Orbiter from the ET are shown in figure 1. At the forward attachment, release is accomplished by the shear-type separation bolt (fig. 2). After the piston shears the bolt shank, it pushes the lower section of the shank free of the spherical bearing and the bottom of the piston stops flush with the outer surface of the bearing. This design results in a dual-shock effect. As the pyrotechnic cartridge pressurizes the volume above the piston, there is a recoil effect. The primary shock, however, is caused by the piston shearing the bolt shank and then stopping as it impacts the shoulder of the shank. At the two aft attachments, a 6.35-centimeter (2.5-inch) frangible nut is used as the release device. After the Orbiter is separated from the ET, doors close to cover the cavities that remain after structural release.

FRANGIBLE NUT - ORBITER SIDE

A primary objective in quickly developing an alternate separation concept was to minimize the impact to the system in terms of design changes to the Orbiter and the ET. To develop, prove, and implement a new separation system, there would have to be virtually no structural changes or significant redesign to either vehicle. By locating the frangible nut on the Orbiter side and providing blast-containment and bolt-reaction capabilities within the existing volume, no changes would be required on the ET side of the separation plane.

The initial focus of attention was to develop a means of blast containment. With increased Orbiter weight being highly undesirable and with a restricted volume to work in, the goal was to develop a relatively lightweight cloth bag container fabricated from Kevlar, a registered DuPont trademark for a family of aromatic polyamide fibers characterized by high tensile strength. The bag was cylindrically constructed with one end closed and the other end secured to a mounting structure by a compressive V-clamp. Figure 3 shows the test configuration and indicates how the bag completely contains the frangible nut and any debris resulting from an explosion.

Initial test objectives were to determine the capability of the fabricated Kevlar material to withstand the explosive elements and to verify the bag retention design. As these tests were being planned and conducted, a design effort to provide a bolt retraction mechanism compatible with the Kevlar blast container was initiated. A series of tests (discussed in the section on test results) was conducted and proved the lightweight Kevlar bag to be very successful; however, the concept was abandoned in favor of a design using the explosive elements on the ET side and the design of the bolt retraction mechanism was stopped.

FRANGIBLE NUT - ET SIDE

A design that relocated the pyrotechnics to the ET side of the separation plane (fig. 4) was chosen as the preferred approach. The primary reasons for this change were to completely remove the explosive shock condition from the Orbiter structure and to provide the allocated Orbiter separation volume for a bolt retraction mechanism. It had become evident in earlier efforts that an acceptable bolt retraction mechanism would require considerable volume and that this would probably be the main design driver. By relocating the frangible nut to the Et side, the bolt could be shortened to a length compatible with retraction into the existing Orbiter volume.

The basic design approach was to machine a slot in the ET yoke fitting for locating the frangible nut. Pyrotechnic ignition wires are routed through a hole in the main attachment bolt from the Orbiter to the frangible nut. An appropriate potting compound is used to secure the wires and to fill the void remaining at the bottom surface. The bottom of the retracted bolt acts as a closeout at the separation plane. A wire-cutting feature was added to the system; this device, upon actuation of the nut pyrotechnics, severs the wires at the bottom of the bolt and results in a smooth closeout surface. A rugged, all-metal blast container lined with an energy-absorbing material to dampen the explosive effects is attached to the yoke fitting and encloses the frangible nut. The bolt is spring-loaded on the underside of the head to provide retract energy.

The initial objectives were to determine the modifications required to the ET yoke fitting and to develop means for blast containment. The test objectives for the first phase were to evaluate the blast container integrity and to obtain engineering data on bolt energy due to release of the 445-kilonewton (100 000-pound) preload. In the second phase of development, a wire-cutting mechanism and a bolt-retract system were added. Both phases of testing were developmental and did not include side loads or other specific conditions existing during flight separation.

TEST FACILITY DESCRIPTION

Testing was conducted in the Pyrotechnics Test Facility of the Thermochemical Test Area at JSC. The primary purpose of the Thermochemical Test Area is to support the development, evaluation, and qualification of spacecraft electrical power, hydraulic, propulsion, and pyrotechnic subsystems.

The Pyrotechnics Test Facility includes the electronics and mechanical shops, an explosives handling and loading room, and four test cells that are used for testing pyrotechnics ranging from a few milligrams of explosive charge to small rocket motors. Ready storage for pyrotechnic igniters and charges is provided by two magazines. One of the test cells is shown in figure 5.

TEST RESULTS

Frangible Nut - Orbiter Side

The first test of the Kevlar blast container used a 1.91-centimeter (0.75-inch) nut with two NASA standard detonators (NSD's). The bag was secured to the test fixture with two hose clamps. In this test, the bag failed where the top was sewn to the cylindrical sleeve. The next bag was reinforced with straps that cross over the top of the bag. A second test used the two NSD's with boosters but without a nut. This bag was secured to the test fixture with a 1.27-centimeter (0.5-inch) stainless steel band using a banding tool. Small penetrations were found in the bag but were not considered an issue because a nut would have absorbed much of the energy of the pyrotechnic fragments.

For the next test, a 5.08-centimeter (2-inch) pyrotechnic-actuated frangible nut was used to test a third bag. This bag was secured to the test fixture with a 1.91-centimeter (0.75-inch) stainless steel band. The bag successfully contained all particles and, at this point, confidence in the bag was high. However, it was determined that the banding tool could not be used for the Shuttle because of access constraints.

A series of four tests using 5.08-centimeter (2-inch) nuts was conducted to develop a three-piece clamp for holding the bag. In the first test, the 0.79-centimeter (0.31-inch) bolts holding the clamp segments failed. High-speed motion pictures indicated two primary dynamics: the pressure wave from the blast loads the entire bag, and the nut halves are propelled radially and strike the clamp. One-centimeter (0.38-inch) bolts were used for the next test. The bag and clamp assembly blew off the fixture because the clamp did not have enough interference with the fixture. A tighter clamp was made and two demonstration tests confirmed the design adequacy. This final configuration is shown in figure 6.

Frangible Nut - ET Side

Two tests of the frangible-nut ET-side configuration have been conducted. The primary objective of the first test was to demonstrate the effectiveness of the steel blast-containment device. A secondary objective was to measure the velocity of the bolt resulting from the release of strain energy. Two carbon rods were placed in the path of the bolt and spaced at a prescribed distance. Electrical current passing through the rods was recorded on high-speed analog tape. Interruption of the signal would signify rod breakage due to bolt travel and provide displacement and time information for calculating velocity. High-speed motion pictures also recorded the motion of the bolt. The test setup is shown in figure 5.

After the nut was separated, the bolt began to spring upward. The first carbon rod was broken; however, the bolt only traveled approximately 3.81 centimeters (1.5 inches). From the motion pictures, it could be seen that the yoke fitting was falling and rotating, possibly binding the bolt.

Inspection of the bolt threads indicated that the nut fragments may have interfered with bolt movement. The blast-containment device was completely effective.

The primary objective of the second test was to determine the performance of the guillotine used to cut the pyrotechnic lead wires. The secondary objective was to determine the effectiveness of the bolt-retracting spring and the bolt catcher. The lead wires were cleanly severed by the guillotine, and the bolt retracted and locked as designed.

SHOCK DATA COMPARISON

Shock-response spectra for the baseline shear bolt and for the frangible-nut ET-side configuration are shown in figure 7. These data were obtained from tests conducted at the prime contractor facility. The test article included a complete forward structural attachment and a representative portion of the Orbiter forward fuselage structure. Also shown in figure 7 is an apparent structural limit for the thermal protection system (TPS) obtained from component tests of TPS tiles. It is evident that the frangible-nut ET-side configuration produces shock levels that are well within the TPS capability boundary. A test of the frangible-nut Orbiter-side configuration had also been planned using this structural representative test article. This test was canceled when the decision was made to minimize the number of mechanical concepts under consideration to reduce shock levels. Modifications to the baseline shear bolt were also tested, and the results are summarized in figure 7.

CONCLUDING REMARKS

Because of pyrotechnic shock generated at the Orbiter forward structural attachment by the baseline pyrotechnic separation bolt, the development of alternative low-shock separation designs was initiated. Two designs, which used a 5.08-centimeter (2-inch) frangible nut as the release device, were tested at JSC. The results of these tests have demonstrated the feasibility of these designs for application to the Orbiter forward attachment. Data from a test of one of the designs at the prime contractor facility have shown that shock levels are substantially reduced and well within the capability of the TPS tiles and the Orbiter avionics equipment located nearby. Additional testing of the frangible-nut ET-side configuration is planned at JSC. This series of tests will include the effects of externally applied loads at separation and will provide additional confidence in this system as a potential substitute for the baseline separation system.

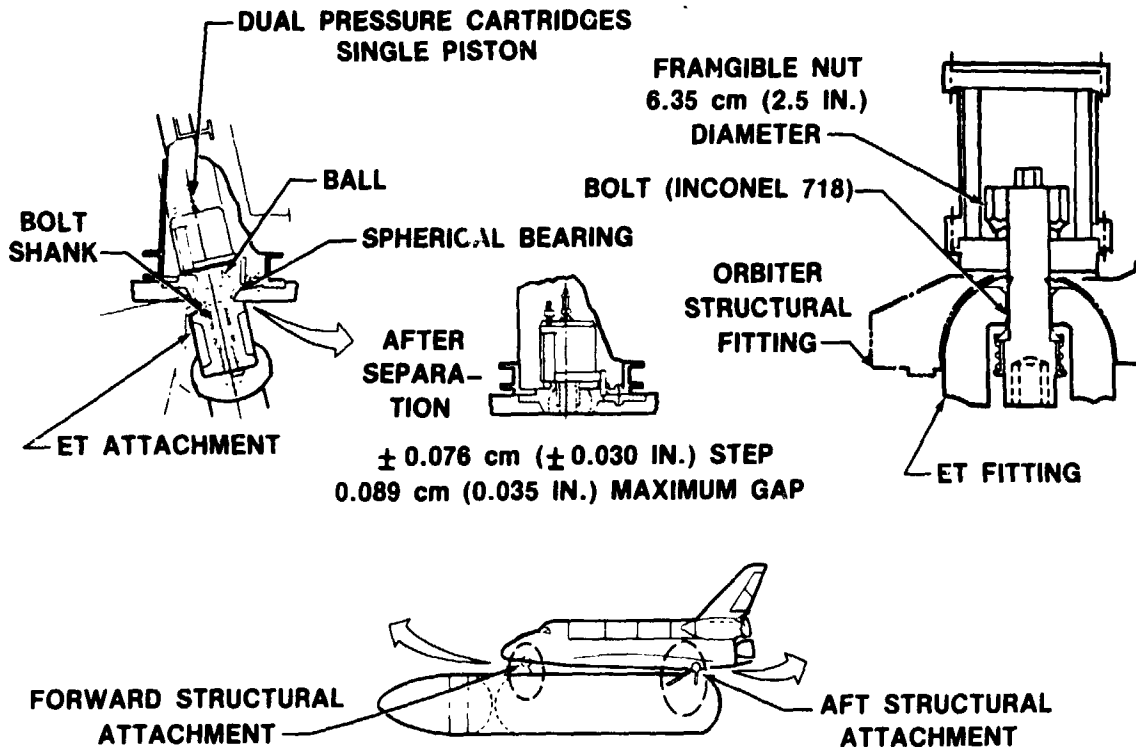


Figure 1.- Orbiter/ET separation system.

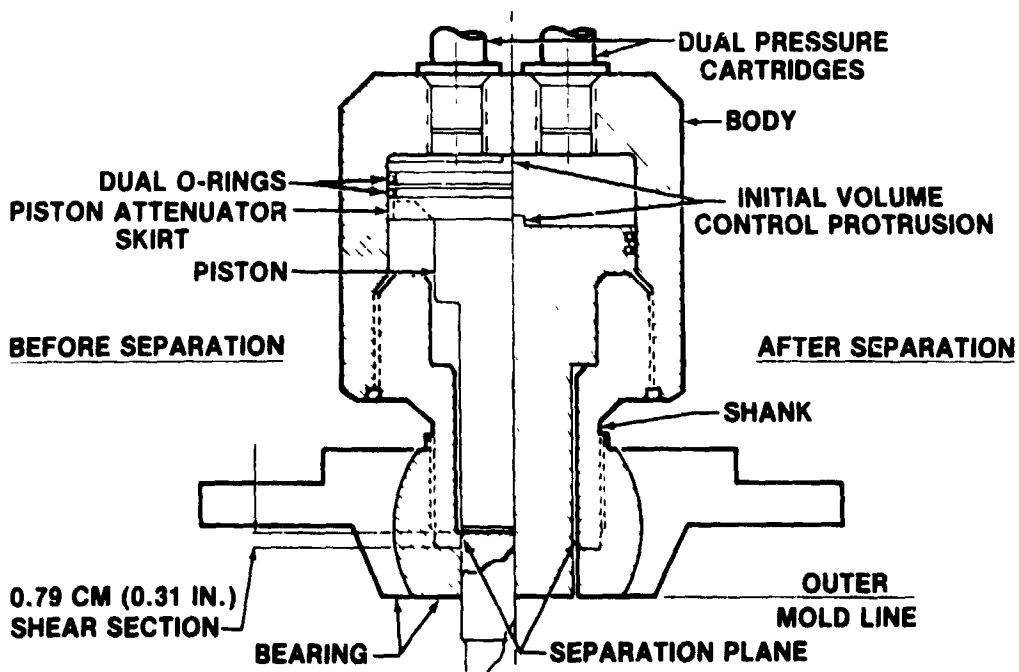


Figure 2.- Shear flange separation bolt.

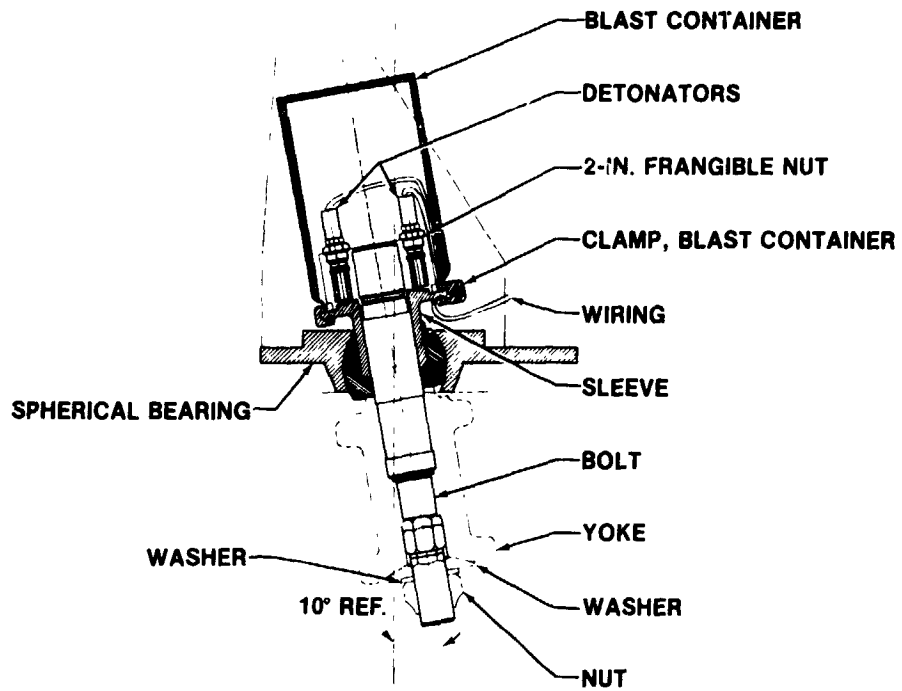
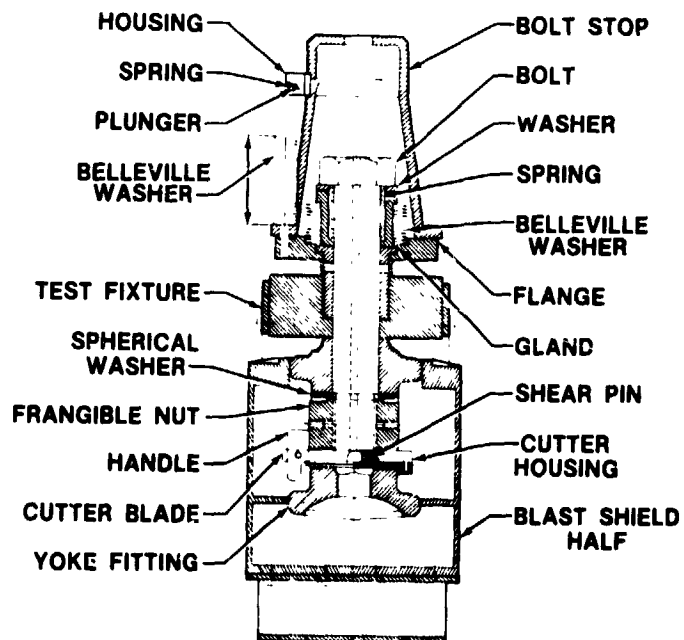


Figure 3.- Frangible-nut Orbiter-side configuration.



SECTION LOOKING OUTBOARD THROUGH
CENTER OF TEST FIXTURE

Figure 4.- Frangible-nut ET-side configuration.



Figure 5.- Frangible-nut ET-side test configuration.

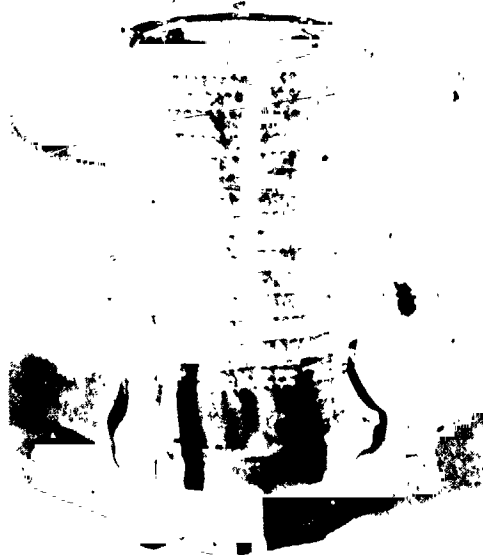


Figure 6.- Frangible-nut Orbiter-side test configuration.

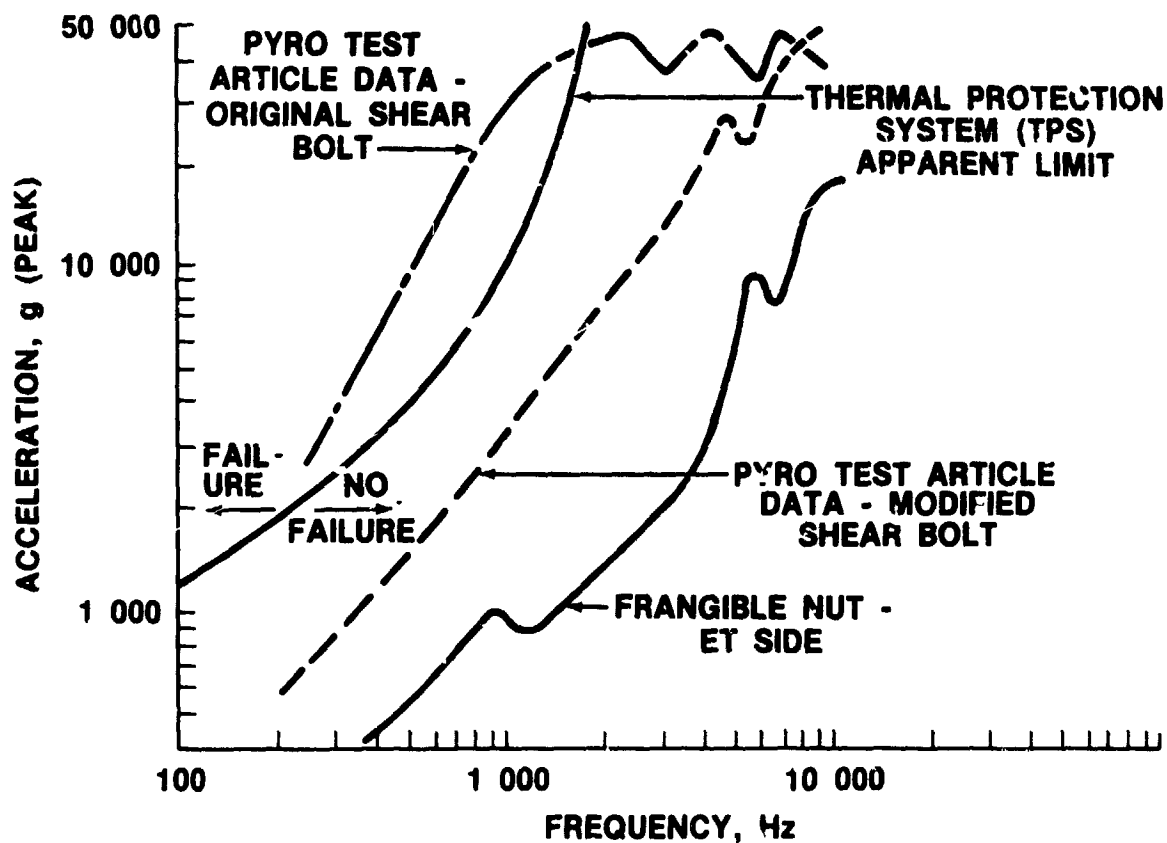


Figure 7.- Pyrotechnic shock-response spectra of the forward separation system.