

DEVELOPMENT OF AN ULTRA-LOW-SHOCK SEPARATION NUT

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ABSTRACT

This paper describes the technical problems encountered in the development of an advanced separation nut design which is capable of sustaining large preload and releasing that load with low level of induced pyrotechnic shock, while demonstrating a tolerance for extremely high shock imposed by other pyrotechnic devices.

INTRODUCTION

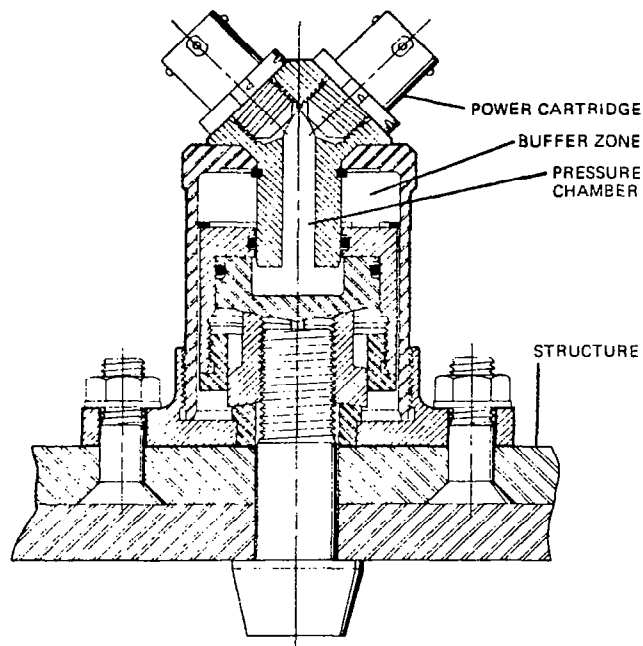
Separation nuts have been used by the aerospace community for over twenty (20) years to achieve remote, rapid and/or simultaneous disassembly of spacecraft and missile components. Separation nuts differ from so-called "frangible" nuts in that the latter depend on a detonation to structurally fail the nut and allow the stud to be released, while in separation nuts, no structural failure is required.

The typical separation nut utilizes a set of threaded collets to engage the threads of the attachment bolt. Those collets are held in position by the relative position of the internal parts of the nut. When separation is desired, the pyrotechnic charge is ignited and the gas thus generated is released into the working volume of the nut and acts upon piston surfaces to cause motion of the internal parts of the nut. This action releases the retaining feature of the collets and allows the separation bolt to be released. Figure 1 shows a standard separation nut before and after actuation.

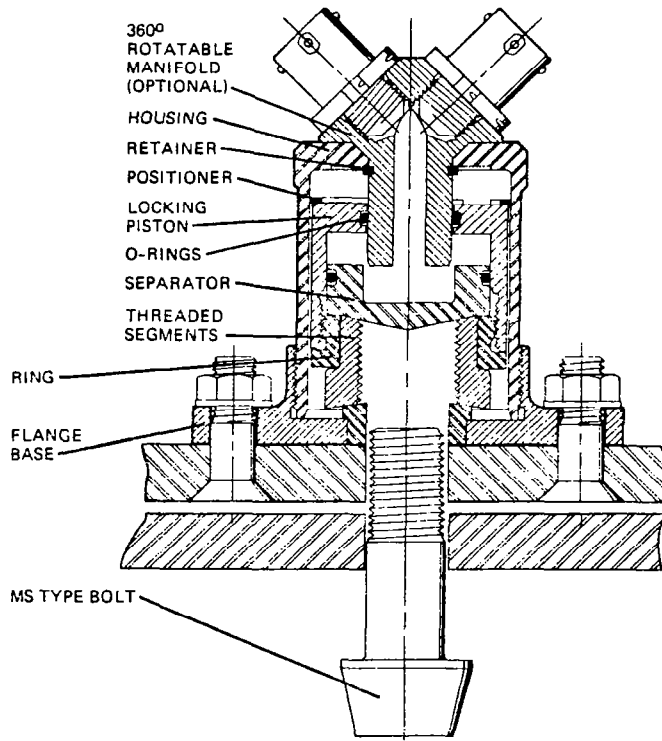
Increasing sophistication of typical modern spacecraft has brought about the utilization of payloads/instruments which are increasingly sensitive to dynamic environments such as the shock induced by pyrotechnically actuated devices. Standard shock isolation techniques are, in many cases, not feasible due to functional constraints such as the required strength and stiffness of the load path from the separation nut mounting surface to the vehicle structure and precise alignment requirements between the sensitive instruments and vehicle structure. Accordingly, virtually the entire burden of limiting the shock level input to sensitive instruments has been placed on the source of shock, the separation nut.

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BEFORE ACTUATION



AFTER ACTUATION

Figure 1. Standard Separation Nut

CONSTRAINTS

A combination of three (3) mutually conflicting requirements has placed the designer of pyro-actuated separation nuts in a rather tightly bounded situation. His design must perform satisfactorily within a requirements "triangle": bounded on one side by the requirement to reliably actuate under the worst combination of loads and environments (including the requirement to demonstrate margin by functioning with underloaded cartridges); bounded on the second side by the requirement to severely limit the pyro shock pulse induced by the device to levels more than an order of magnitude lower than those generated by previously produced devices (such as the separation nut of Figure 1); and bounded on the third side by the requirement that the device must not prematurely actuate at shock levels similar to those which it itself produces upon actuation.

DESIGN

One such device, designed to the mutually conflicting requirements of the above-mentioned triangle, is the separation nut developed by Hi-Shear Corporation for General Electric for use in satellite-to-satellite separation and in boost-vehicle separation on the Air Force's DSCS-III Communications Satellite.

Early in the development program, the Hi-Shear 9400 Series Standard low-shock separation nut was selected for DSCS-III Spacecraft separation function to retain and release a 1/2-inch bolt. The cartridge charge was sized such that the minimum output charge which would reliably actuate the nut (under worst-case temperature and preload conditions) was defined as the 80% output charge, and 100% charge was determined accordingly. This is due to the requirement that, during qualification, the nut must demonstrate release at maximum preload and worst-case temperature utilizing a single cartridge loaded to only 80% of nominal output charge.

As a schedule expedient, induced pyro shock testing was performed on a vehicle simulator using engineering separation nuts and cartridges to determine response at critical component locations. These test data defined the shock qualification requirements for critical components.

Subsequently, separation nuts and cartridges were fabricated and subjected to component qualification testing. A failure to release with single 80% output charge cartridge was incurred. Two approaches were available to cause release at specified conditions:

- o Increase output charge of cartridge
- o Cause separation nut to release at lower applied pressure

Because the component qualification shock environment for panel-mounted components had been established at the low energy level, additional output charge could not be added without providing for energy absorption in the separation nut itself. Therefore, effort was directed towards reducing required actuation pressure in the separation nut.

Actuation pressure was approximately 34.47 megapascals (5000 psi) in the as-produced separation nut. Some reduction in actuation pressure was realized by burnishing the dry film lubricant which is applied to segments, key seat and retainer ring. Burnishing was accomplished by cold gas release of the nut while at maximum preload. The retaining ring was undercut slightly to provide easier release.

An energy-absorbing honeycomb cushion was added to the base to reduce shock induced by impact of piston on the housing.

The segments were "slotted" at the retaining ring interface area to reduce area of contact and permit better compliance at that interface.

Figure 2 shows the separation nut configuration with changes incorporated.

The combination of changes reduced actuation pressure to approximately 3.45 - 4.83 megapascals (500-700 psi), and reduced the shock-generating capability of the nut.

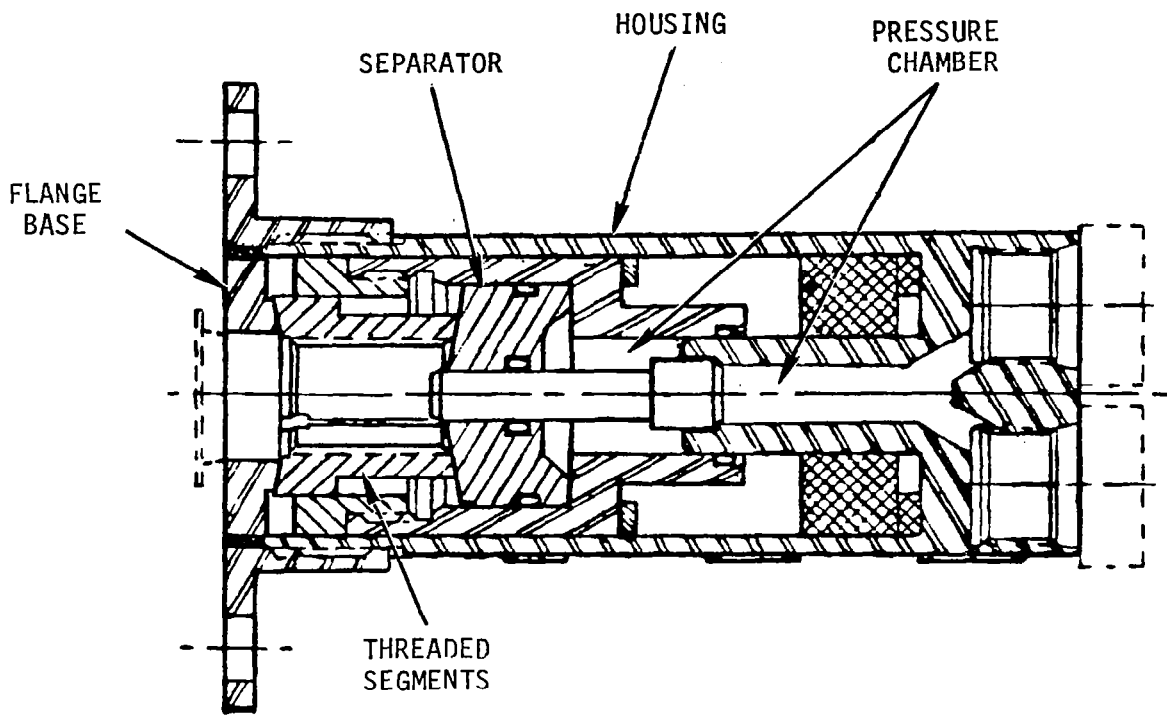
Separation nuts were built to the modified configuration for component qualification testing. Again the separation nut failed. Mode of failure was inadvertent release in pyro shock environment, the second leg of the requirements triangle. Qualification test shock requirement was 2300 g at 1300 Hz.

All effort was now concentrated on construction of a dynamic model of the separation nut.

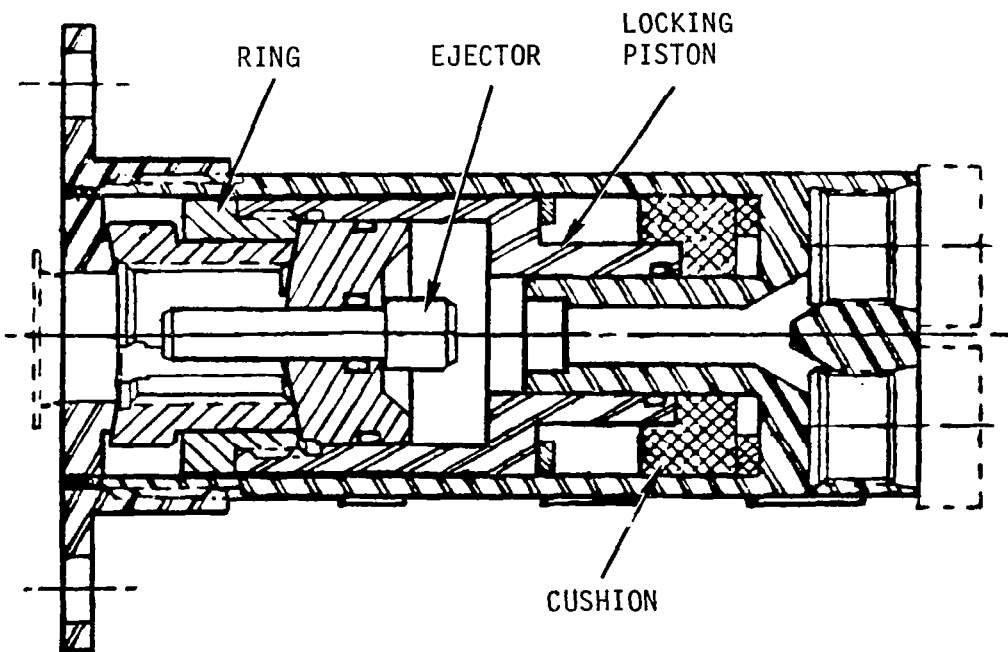
DESIGN ANALYSIS

An analysis of the separation nut was performed to acquire additional understanding of the phenomena affecting operation of the nut and to provide quantitative evaluation of design modification.

Physical evidence indicated that rotation of segments under preload may provide a component of the preload acting in a direction to "push" the retaining ring off the segments. Therefore, the separation nut was modelled to investigate segment rotation. Additionally, a theory that deflection of housing under shock load may permit contact between the housing and piston, causing the piston retaining ring to "walk" off the segment, was considered in the analysis.



BEFORE ACTUATION



AFTER ACTUATION

Figure 2. Initial Separation Nut Design

The analysis used the NASTRAN finite element method. A 3-D model of the separation nut was required to account for the fact that the nut is segmented. Symmetry permitted modelling of only half of the nut. Careful selection of boundary conditions for the many elements of the nut was required since in normal functioning, parts slip with respect to one another.

Results of the analysis showed that the segments did indeed rotate under preload and predispose the nut to premature release. The analysis also confirmed that the retaining ring slips 0.025mm (.001 inches) when the top of the case moves laterally 0.229mm (.009 inches) as was measured in shock testing of the original design. A design fix, increasing the length of engagement between segments and retaining ring, was prepared. This was done by increasing the length of ring. The increased interface length stabilized the segments and inhibited rotation under load. Indeed measurements taken later in the program showed segment cocking of 0.19 degrees average compared to a predicted value of 0.18 degrees.

FINAL DESIGN

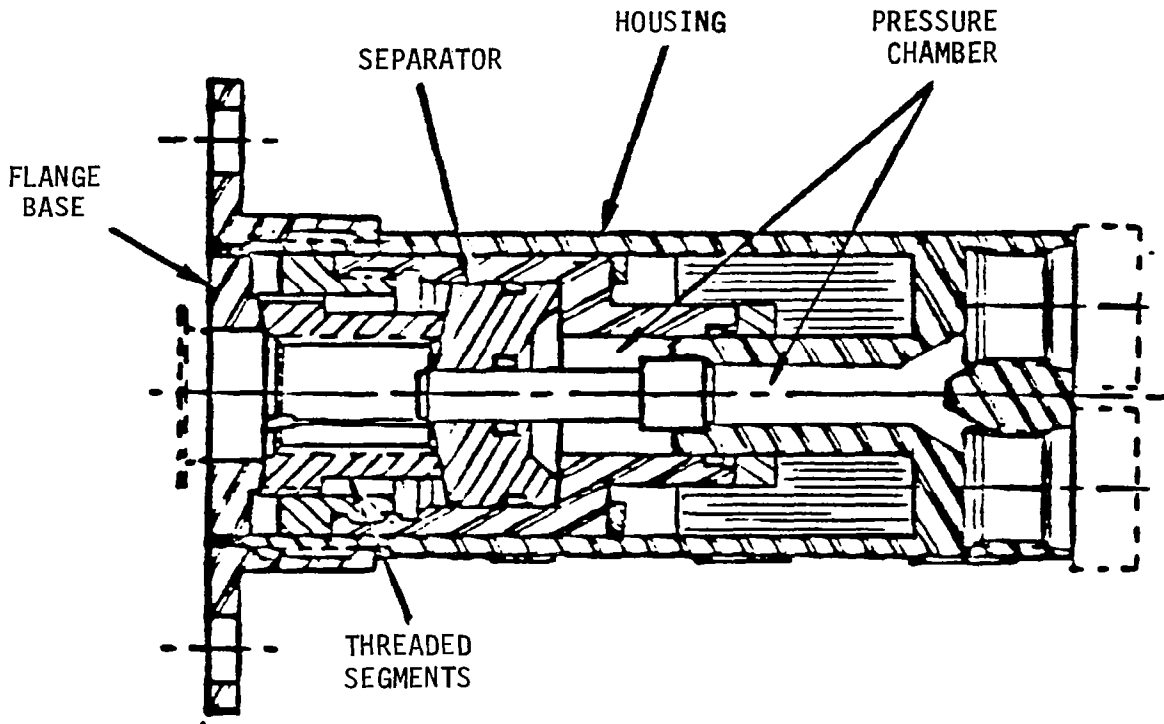
Increasing the length of interface between segments and ring increased pressure required to actuate the separation. Consequently, more output charge was required for reliable function. It was therefore necessary to absorb more energy within the separation nut to avoid increasing the baseline vehicle pyro shock environment which had been established early in the program.

The aluminum honeycomb energy absorber was redesigned for the nut case to perform two functions. The primary function was to limit shock induced by actuation of the nut. The second function was to bear against the piston in the assembled state to provide added insurance that the piston would not move during preloading and environmental exposure. Figure 3 shows the final configuration with extended honeycomb.

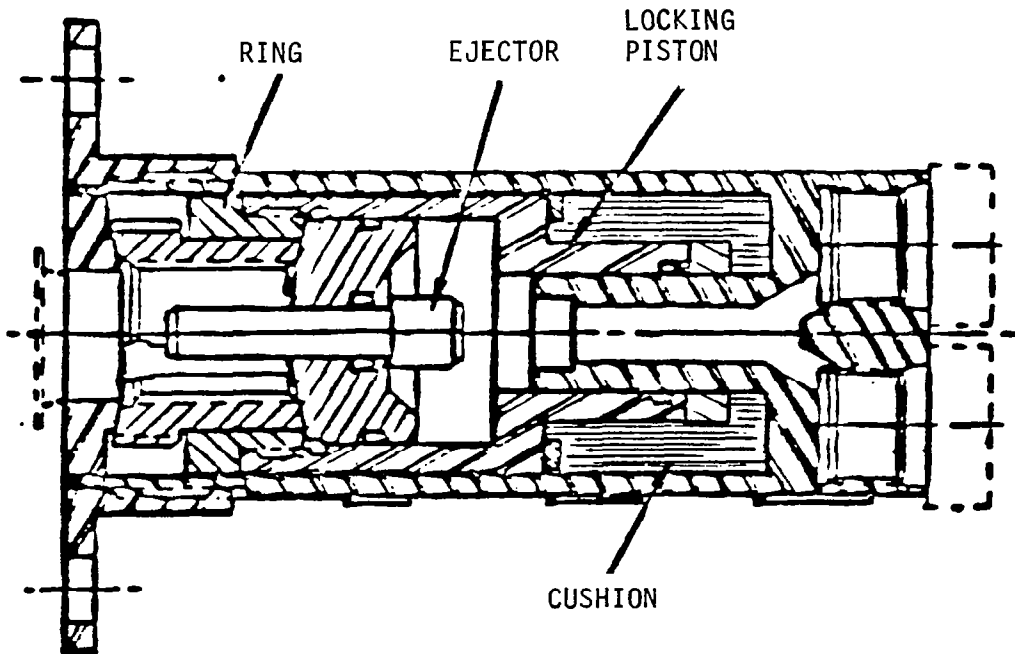
Engineering tests of this configuration in dynamic environments were successful. Engineering tests were also performed to verify that shock induced into the spacecraft by this design was within the program baseline. Again, the tests showed the design was good.

Figures 4 and 5 show comparative induced shock data at 2 vehicle locations for the standard low-shock separation nut and the ultra-low-shock separation nut. A new lot of hardware was procured and 27 separation nuts were subjected to qualification test environments including a shock test of 2300 g at 1300 Hz. Each unit was X-rayed after each dynamic environment.

There was no relative motion between segments and ring in any of the test units. All units survived environmental exposure and functioned normally.



BEFORE ACTUATION



AFTER ACTUATION

Figure 3. Final Separation Nut Design

SHOCK COMPARISON TESTS

STANDARD LOW SHOCK NUT (LSN)

AND

ULTRA LOW SHOCK NUT (ULSN)

STA 4X
MAXIMUM SPECTRUM OF 3 FIRINGS

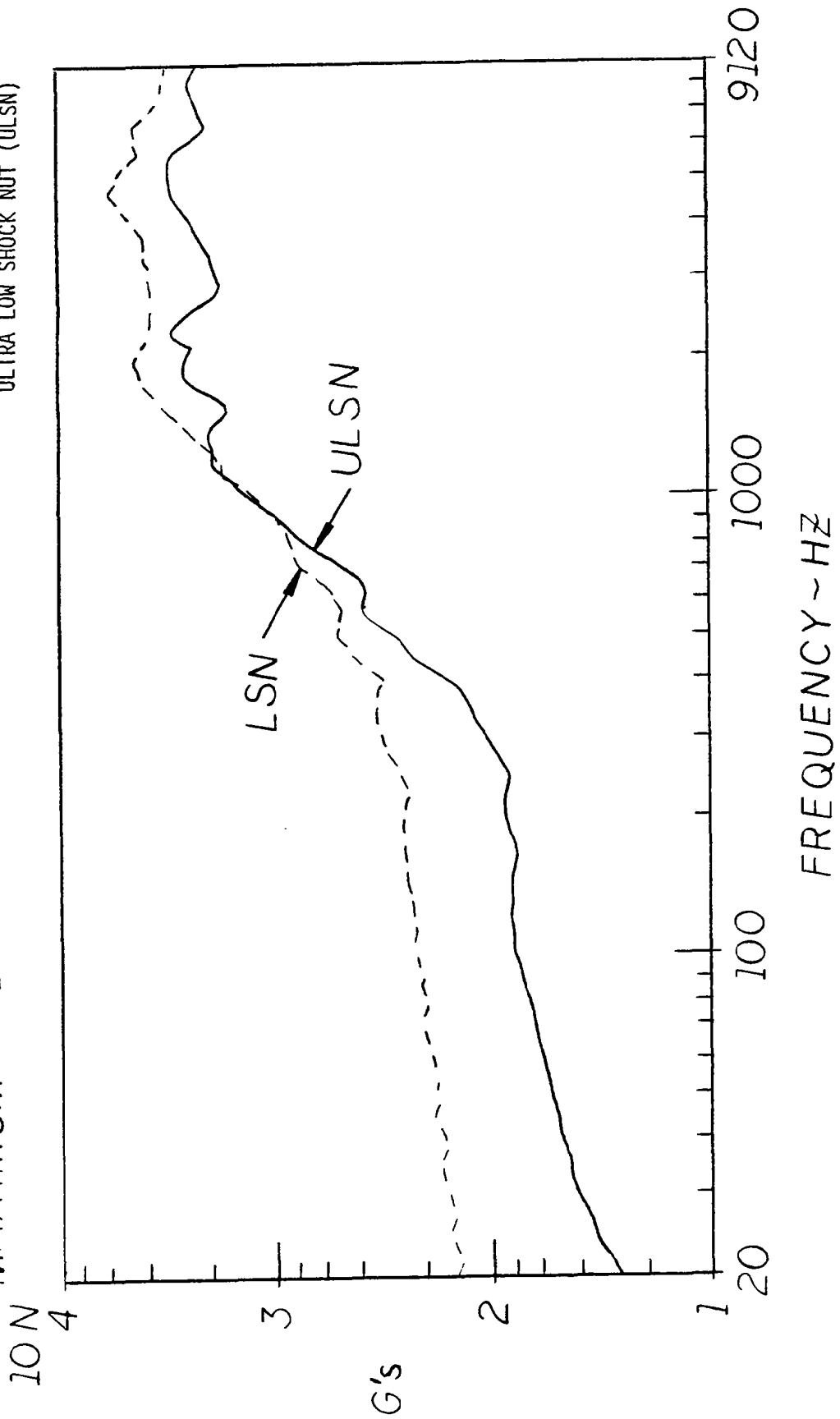
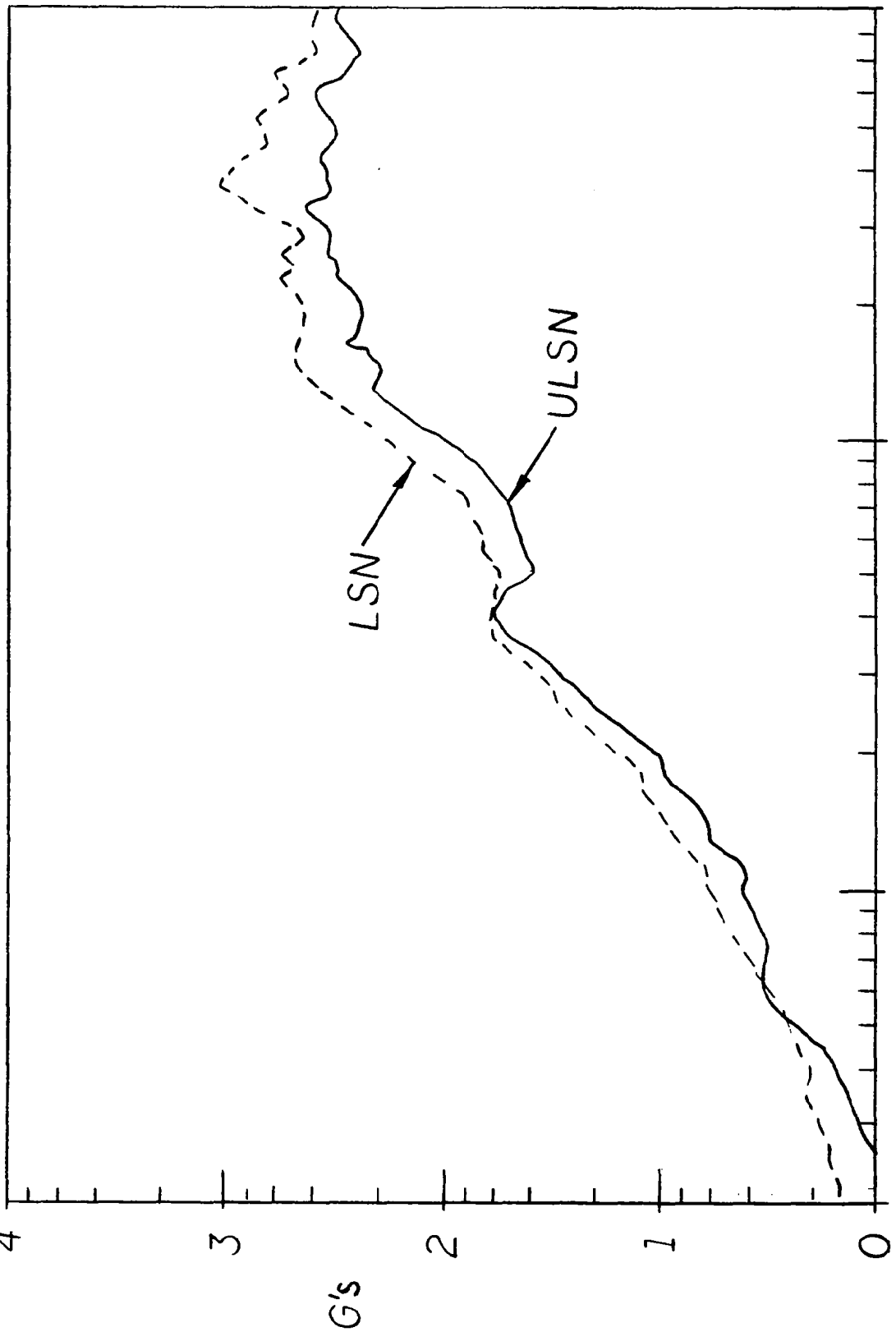


Figure 4. Station 4X Shock Comparison Tests

STANDARD LOW SHOCK NUT (LSN)
AND
ULTRA LOW SHOCK NUT (ULSN)

STA 17 Y
MAXIMUM SPECTRUM 3 FIRINGS

ION



9120
1000
100
20
FREQUENCY ~ HZ

Figure 5. Station 17Y Shock Comparison Tests

VALIDATION OF DESIGN AT HIGHER SHOCK LEVEL

Subsequent to the qualification of the separation nut to the 2300-g environment, a new and much more severe shock environment of 4500 g peak, as defined in Figure 6, was identified for a second candidate booster combination. A new lot of hardware was prepared and tested to the increased environmental level. Qualification testing was completed successfully without problems.

ACKNOWLEDGEMENT

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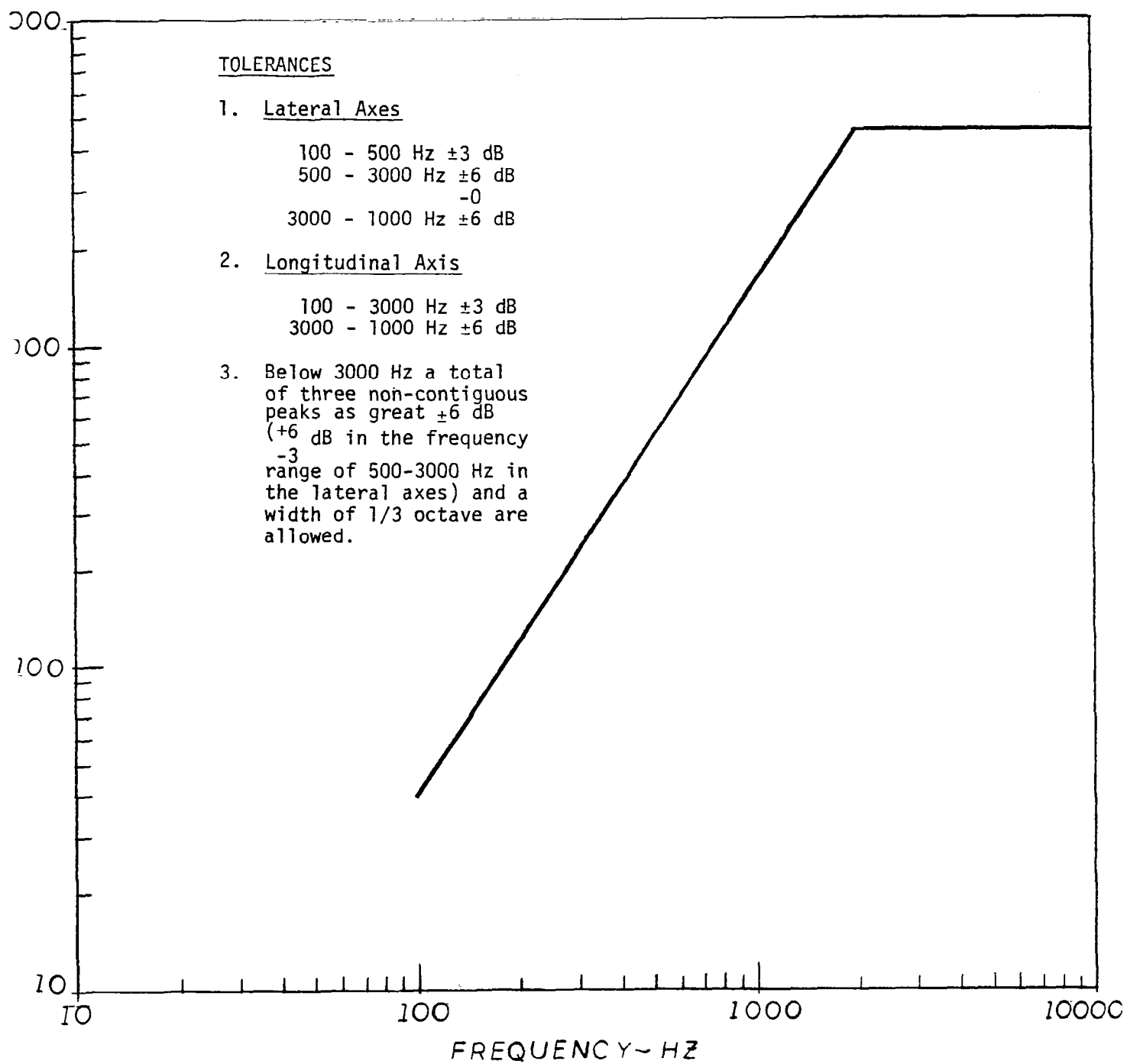


Figure 6. DSCS-III 1/2-in Separation Nut Shock Response Spectrum (Q = 10)

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Mr. Wobkenberg has 22 years' experience in the design, development, and test of aerospace components and subsystems, including satellite recovery systems, spacecraft separation subsystems, solar array drive mechanisms, and ordnance-actuated devices. He received his B.S. degree in Aeronautical Engineering from Purdue University in 1959.

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