N76-28289

DESIGN EVOLUTION OF A LOW SHOCK RELEASE NUT*

By David H. Otth - Jet Propulsion Laboratory
and
William Gordon - Hi-Shear Corporation

ABSTRACT

Design improvements and detailed functional analyses are reviewed to trace the development of a pyro-actuated release device with segmented thread design from its intermediate design into one that reduces the levels of shock spectra generated during its operation by 50%. Comparisons of shock output and internal load distribution are presented, along with descriptions of mechanical operation for both designs. Results also show the potential areas where design development activity can gain further progress in lowering actuation shock levels.

INTRODUCTION

Pyro-actuated release device configurations with launch load carrying capability for spacecraft or expended-stage separation plane designs characteristically reduce their installed preloads to zero within millisecond function times to complete interface separations. This design feature provides high mechanical and dynamic efficiency for separation but generates high frequency and magnitude shock levels which are transmitted through the interface to the adjacent structure. If electronic packaging, attitude control gyros, or science instruments sensitive to shock are nearby, this side effect may be undesirable depending upon the magnitude of shock spectra received.

Development of the release device for the Viking Orbiter 1975 (VO'75) separation interfaces brought about an understanding of the release forces and internal dynamic action related to shock generation. Subsequent design improvements that significantly reduced shock levels were then incorporated into the release device for the Mariner Jupiter/Saturn 1977 (MJS'77) spacecraft interface. Both designs involve a segmented nut that releases 1/2-20 bolts and, for this report, are individually presented in two sections. Discussions are limited, however, to findings and design improvements that resulted in lowering shock during operation.

RELEASE DEVICE FOR VO'75

Description of Operation and Development Program

The Viking Orbiter 1975 release mechanism was a dual squib segmented nut design that mated with a 1/2-20 strain gaged bolt and was utilized on both Orbiter separation interfaces (Viking Lander adapter and spacecraft adapter). The release nut assembly provided an 11,800-lb tension launch preload at four interface hardpoints coincident with each VO'75 separation plane. Upon simultaneous commands to eight squibs, all four mechanisms functioned within 6 milliseconds to reduce hardpoint preloads to zero and eject bolts, thereby completing interface separation.

---

*This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NAS 7-100, sponsored by the National Aeronautics and Space Administration.

The Viking device was a modified version of the segmented nut design used on the Surveyor Program with improvements in areas of materials, configuration, and lubrication. These improvements were made during the development program and were initiated to improve internal load distribution, low-temperature performance, and reusability as related to repeated pneumatic testing. A significant portion of the development program was devoted to understanding the source and distribution of the 100,000-g peak accelerometer shock response generated during its operation and to reducing levels as electronic bays were installed adjacent to the separation plane hardpoints. Reducing the shock output required extensive modification, which was not feasible for VO'75, but an understanding of the source of shock and the distribution of loads was obtained. Design changes that would result in reduced shock levels were implemented on the release nut for MJS'77 and are discussed in detail in the next section.

Referring to Figure 1, the VO'75 release nut basically consists of three threaded segments positioned by the base key seat, locking piston, and separator. When the release nut is preloaded, the bolt load is reacted out within the assembly into axial loads, which are parallel to the bolt axis, and lateral loads, generated by the 60-degree thread angle, which are perpendicular to the bolt axis. The axial portion of the bolt load is transferred to the base key seat and the bolt's lateral load is transferred through the segment lands to mating lands in the locking piston. The bolt ejector is contained in the separator and can add velocity to the bolt only after the bolt has been released. The release nut is operated by pneumatic or squib pressure, which drives the locking piston forward, thereby allowing the segments to move radially outward and release the bolt. The pressurized separator keeps the segments out after release by applying a radial load to the segments through the angled interfaces of the separator and base key seat. The true-arc ring is used for initial positioning of the separator and segments relative to the piston lands during assembly and the O-ring's limit outgassing of squib contaminants.

Distribution of Loads

The significant design changes that resulted in lowering actuation shock levels were based upon an understanding of the preload distribution and stresses on the segments and locking piston within the release nut. For a given bolt preload, the load distribution on a threaded segment is described with the aid of Figure 2. The axial portion of the load is compressive in nature and is reacted out into the base key seat. This component of the load acts along a well defined path and therefore requires little description. However, the 60-degree included angle on the bolt and segment threads generates a large lateral component whose load path is not precisely known.

The exact position and shape of the segment load distribution are only generally known; that is, the first few threads carry the majority of the preload. In addition, the reactive load to the piston is also a distribution, but again shape and exact location are unknown. The end result is the inability to determine a precise value for (1) the maximum bending stress on the segments, which occurs at the minimum thread diameter adjacent to the front lands, shown as point A in the close-up portion of Figure 2, and

(2) the piston hoop and bending stress, as shown in Figure 3. To circumvent the problem of inexact load description, a comparative analysis was conducted using point loading rather than distributions and determining the segment bending stress at point A. The bending stress established was given a value of 1.0 and was compared to recalculated stresses when (1) land areas were increased and moved forward toward the base, (2) the first few threads were moved in line with the center of land areas, and (3) segment thickness was increased in the area of highest bending stress (see Table 1). The main design improvement made for VO'75 was increasing the segment thickness behind the first land to lower bending stresses. Aligning the first few threads with the center of land areas and moving the lands forward required extensive redesign, and both changes were incorporated into the MJS'77 configuration, which also eliminated the lightly loaded rear land. These changes not only reduced internal stresses by 60% but lowered piston deflection and changed the segment configuration, which were key factors in reducing actuation shock, as will be discussed in the second section.

Table 1 also shows that although bending stresses were reduced for VO'75, deflection was not, at least from segment changes. On the other hand, the piston's first land area could be easily increased and was, by 0.050", to decrease piston deflection by 20%. The objective was to lower the open end "belling" of the piston, as shown in Figure 3, and thereby the "ramp effect" configuration between the piston and segment lands. This in turn lowered the threshold of "release pressure" and increased functional margins. Moreover, further reductions in piston deflections were possible and were implemented later for the MJS device to lower the squib energy needed for operation and lower shock.

Another hardware change that resulted in lowering actuation pressures was a combination of materials selected to withstand repeated pneumatic actuation without dimensional changes and an improved moly-disulfide coating. The coating was used on the threaded segments and piston to reduce the coefficient of friction between mating surfaces. The friction coefficient was reduced further by burnishing the land areas prior to assembly and then during two pneumatic actuations prior to flight. A 15% reduction in threshold pressure was obtained by using this process, which again increased functional margin or allowed lower squib energy to be used for operation.

Sources of Shock

The impact of the piston on the base, the strain energy release of the bolt from the segments, and squib firing contribute to the high-level shock generated during operation. The VO'75 development program identified the individual contribution of each source in order to determine those areas where redesign or modification could reduce shock levels. The release device was mounted to a flight-type spacecraft structure with three electronic bays and was instrumented with shock accelerometers located next to the device.

A series of shock signatures were generated by using a number of release nuts actuated with pneumatic, hydraulic, or single and dual squib pressures. The test results have been summarized in Table 2, which gives the individual contribution of shock sources that result in a 100,000-g peak shock load next to the device. Varying squib loads changed the shock levels by 15%, while hydraulic actuations of the nut which drastically slowed down the piston velocity (compared to squib actuations) indicated that the major shock source was piston impact and represented 60% of the total. This was verified by using Fastax camera coverage that determined the piston velocity in excess of 250 feet per second prior to impact. Using the initial piston velocity and the measured penetration of the piston into a steel base, the deceleration was calculated to be on the order of 60 000 g.

Lowering Shock Levels

Figure 2 shows that shock output can be readily lowered by reducing squib loading and damping piston impact, assuming that methods to reduce the strain energy release are not convenient. By using the load distribution analyses, a new segment configuration was designed having the same preload capability but requiring a more compact and lightweight piston. The new configuration also provided room within the release nut to design a method of reducing piston impact. Damping as well as reversing the direction of piston impact, along with lowering the threshold release forces to permit operation with VO'75 squibs, were the design goals of the low shock release nut.

RELEASE DEVICE FOR MJS'77

Design Features

Concurrent with the effort described for the VO'75 program, the need for an improved release nut design that inherently provided reduced shock levels was recognized. Development work that ensued included design, fabrication, and testing of three different nut configurations that followed the basic bolt retention method used on Surveyor and VO'75. These were tested and evaluated on the basis of several relevant factors, including simplicity, cost, weight, producibility, and the reduction of shock output. The resulting low shock design, depicted in Figure 4, was selected for the MJS'77 program.

The load distribution analyses of the Viking development program led to a further revision of the VO'75 segment, moving the lands toward the base to react against the thread radial loading induced in the first few threads. The second set of lands, located where little or no radial loading exists, were eliminated. The balance of the changes involved those parts which retain the segments and a lighter two-piece piston assembly to mate with the new segment design.

With the primary shock-generating event in the operation of previous release nuts being the impact of the piston with the base, two methods of eliminating this collision were employed. First, the piston was driven away from the base and secondly, it was brought to rest through mechanical and squib gas damping. Reversing the piston direction also aided in lowering threshold release forces as less energy was required to back off the ramp configuration between segment and piston lands caused by "open end" belling. Thus, the same release pressure was obtained with a smaller piston.

Description of Operation

As can be seen in the installed view of Figure 4, the segments are retained by the piston, base key seat, and separator. The separator, similar to that previously used, bears on the upper ends of the segments, helping to stabilize and align them as well as forcing them apart when squib pressure is introduced above the separator. An optional ejector pin is shown that pushes the bolt out of the nut, again when propelled by squib pressure. Unlike the VO'75 design, the pressurized gases are introduced between the separator and piston rather than on top of the piston. This results in the piston being driven away from the base of the nut and allows the segments to move radially outwards. At the same time, gas pressure acts on the separator and ejector, forcing them against the segment and bolt respectively. After the piston has moved sufficiently to release the segments, the lock piston ring contacts the separator. The collision occurs in such a way as to avoid transmitting shock into the adjacent structure as before.

A comparison of the effective pressure area of the piston and separators shows that the separator has more effective area than the piston. This additional area provides a force which acts to decelerate the piston and separator after the piston strikes the separator. The separator is momentarily unseated from the top of the segments due to the inertia of the piston. The major portion of the shock energy in the piston is absorbed during upward motion of piston and separator. The space above the piston is ideally sized such that the two components stop their upward motion due to the pressure area differential, then are forced downward until the separator again seats on the top of the segments. This final seating does generate some shock but significantly less than the direct collision of the piston and base.

Comparison of Shock Levels

The VO'75 device and MJS'77 low shock design were evaluated comparatively on a full-scale flight-type spacecraft structure with electronic bays. Shock signatures were obtained from accelerometers mounted within the electronic bays. The results have been presented as shock spectra, which show peak structural response (G's) versus frequency (Hz). The structural response is derived from the accelerometer peak g time trace, frequency, and a structural amplification factor (Q) of 20. The end result is a convenient representation of total shock content, transferred to the structure in terms of peak G shock and frequency.

Referring to Figure 5, the peak G level of the low shock device is 50% less than that of the VO'75 design as recorded within the electronic bay. If the MJS device was not hard-mounted to the structure but allowed to rebound off the structure after functioning, a 70% reduction in shock spectra was obtained. The same mounting scheme was used for the VO'75 device, but no appreciable reductions were recorded.

CONCLUDING REMARKS

Significant reductions in shock response have been achieved; however, further reductions may be possible by lowering the shock contributions caused by preload release and squib actuation. Although lowering squib energy was not a design goal for MJS'77, reduction of the release force was achieved. Future configurations which are not limited to a specific device diameter can incorporate larger piston diameters and capitalize on the lower release forces. Large areas will allow release pressures to be obtained with less squib energy. As further improvements lower actuation shock, more compact packaging of separation plane hardpoints with electronic bays or science can occur.

Table 1. Segment stresses and piston deflection vs. segment configurations

Configuration	Segment Bending Stress Factors [a]	Open End Piston Deflection, inches
1) Surveyor segment design	1.0	0.00252
2) Increase segment thickness [b]	0.46	0.00252
3) Align first threads with center of land plus (2) above	0.39	0.00194
4) Move land forward plus (2) and (3) above[c]	0.32	0.00173

[a] Represents maximum bending stress comparisons.
[b] Between lands, as was done for VO'75 segment design.
[c] This represents MJS'77 segment design.

Table 2. VO'75 release device shock sources and contribution

Source Item	Accelerometer Response Next to Device	
	g's	Contribution, %
Squib firing	15,000	15
Piston impact	60,000	60
Strain energy release of preload	25,000	25
Total assembly	100,000	100

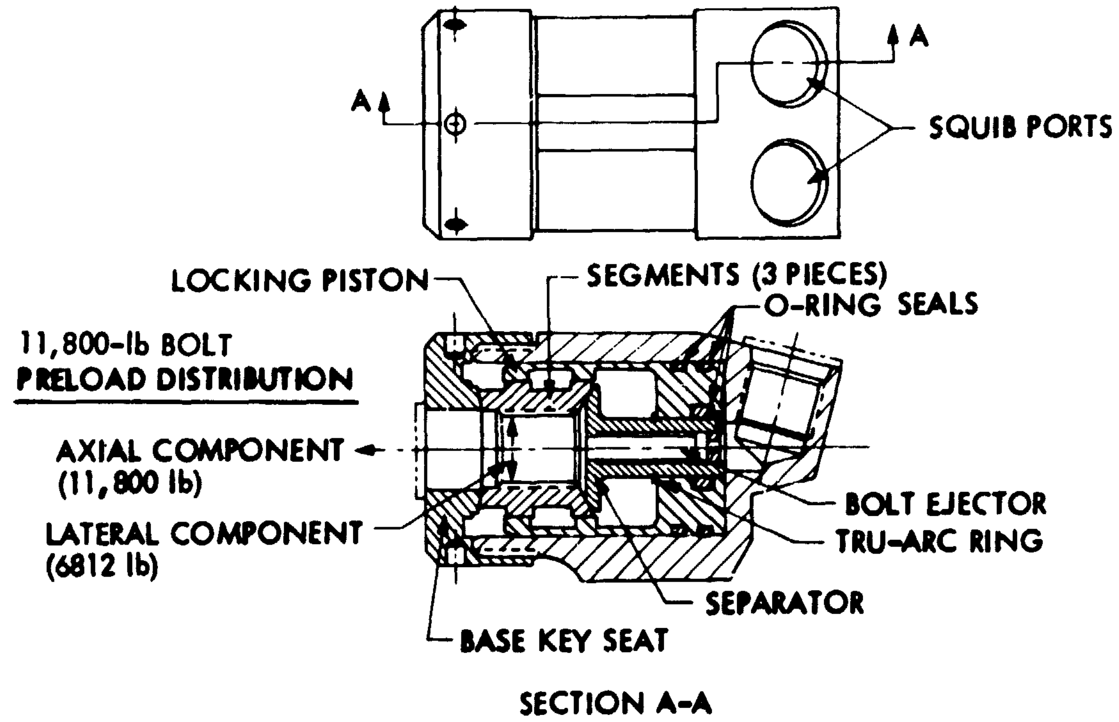


Figure 1. VO'75 release nut assembly cross section

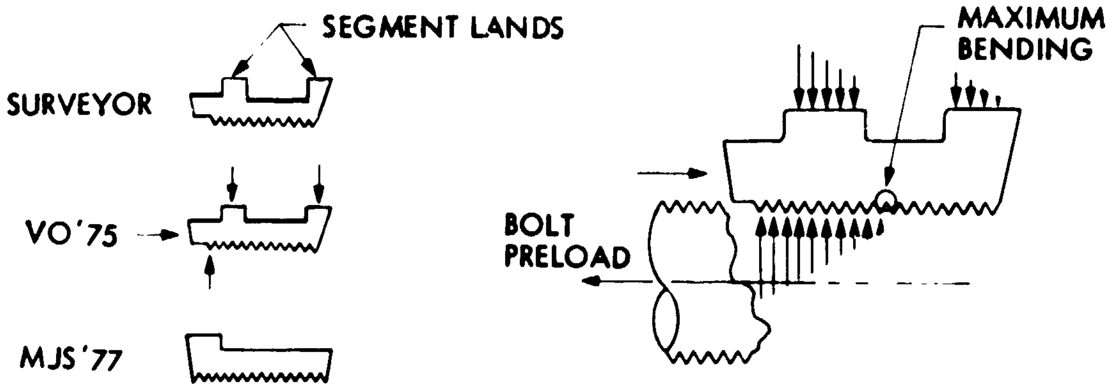


Figure. 2. Cross section of segment designs showing load distribution

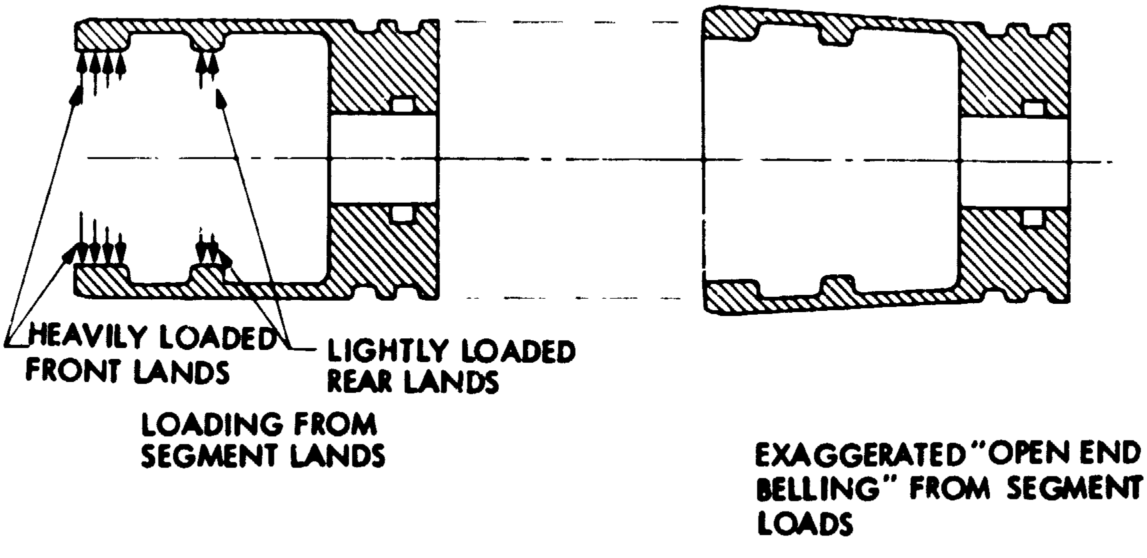
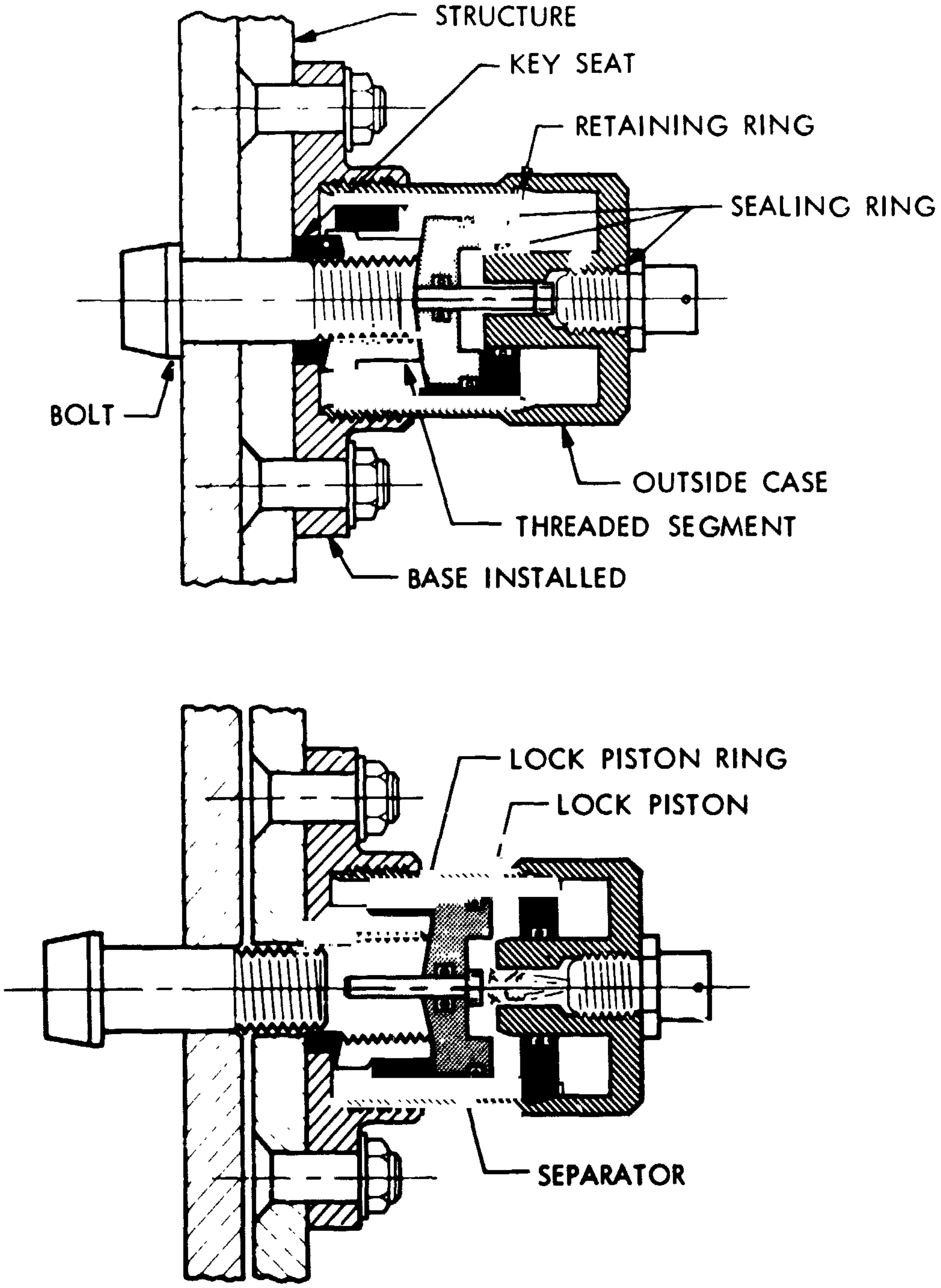


Figure 3. Piston cross sections showing loading and belling



SEPARATED

1. LOCK PISTON MOVES AWAY FROM STRUCTURE TO UNLOCK THREADED SEGMENTS.
2. SEGMENTS DISPLACE RADIALLY AWAY FROM BOLT.
3. SEPARATOR PISTON LOCKS SEGMENTS IN OPEN POSITION.

Figure 4. MJS'77 low shock release nut

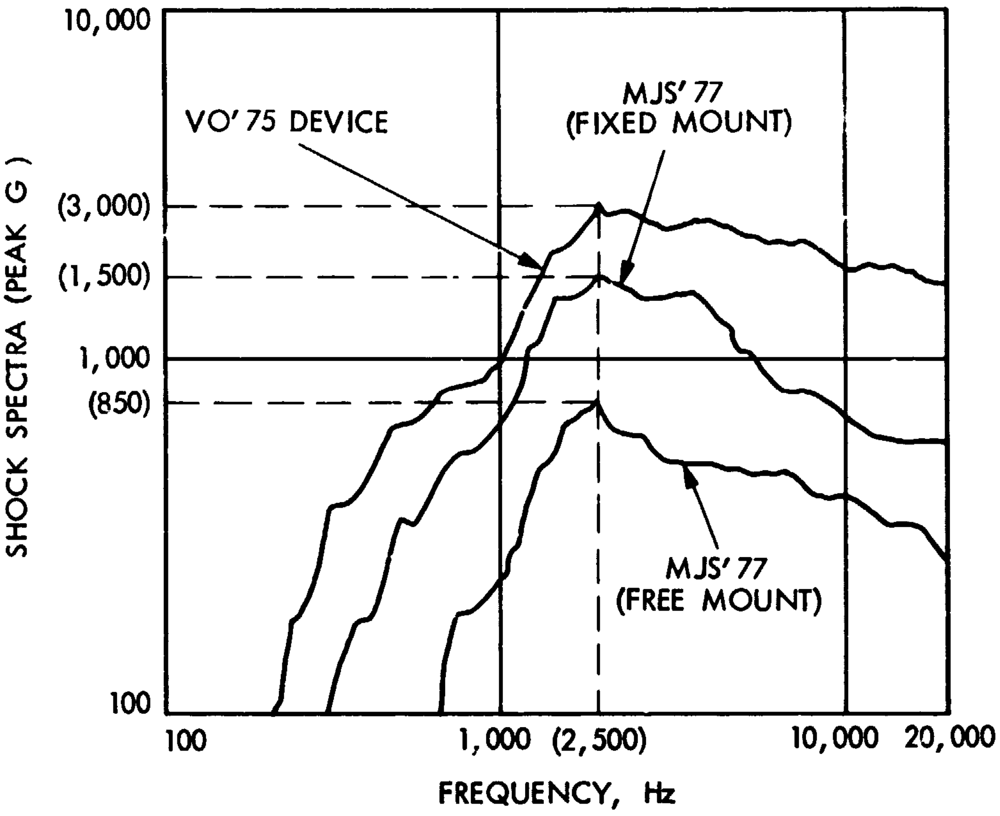


Figure 5. Comparison of peak G shock spectra generated by VO'75 and MJS'77 low shock device vs. frequency