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PIN PULLER IMPACT SHOCK ATTENUATION

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ABSTRACT

An investigation leading to the design of a pin arresting mechanism for a pyrotechnically actuated pin puller is reviewed. The investigative approach is discussed and the impact shock test results for various candidate designs are presented. The selected pin arresting design reduced the peak value of the shock response spectrum by five to one.

INTRODUCTION

Pin pullers have gained industry wide acceptance as a highly reliable release mechanism for spacecraft deployables. Frequently, the deployable is preloaded to the spacecraft primary structure to prevent excessive vibration amplification during ascent. Consequently, high energy pyrotechnic devices are required to overcome the high release pin friction accompanying the high preload. As a result, the pyrotechnic device imparts high level energy to the release pin, which usually must be stopped in a relatively short distance. The short stopping distance in conjunction with the high preload between the spacecraft and the deployable allows time for the pin arresting impact shock to be transmitted to the deployable before separation can be achieved. Many deployables, such as solar array panels for example, cannot tolerate high shock levels; hence, pin arresting mechanisms which effectively absorb shock energy are required.

This paper summarizes a brief investigation of a pin arresting mechanism which would meet a given set of shock spectrum requirements when applied to an existing pin puller design.

PIN PULLER IMPACT SHOCK

Pin Puller Design

The design of the release mechanism for which this investigation was conducted is shown in Figure 1. The mechanism has dual pin pullers, each of which is actuated by dual pyrotechnic squibs. At the end of the unit, the pin pullers release a toggle bolt which is holding the deployable to the spacecraft structure via a preload of [illegible]400 pounds. The particular deployable in this case contained electronic circuits which were sensitive to shock spectrum in the 1 to 5 kilohertz range. The relatively long mechanism body between the deployable and the squib was intended to attenuate the impact shock transmitted to the deployable. However, as the data will show, resonance in this section actually amplified the impact shock.

The initial design of the pin puller arresting mechanism consisted of an aluminum ferrule impacting a swaging collar, as shown in Figure 2. Although this design had been satisfactorily proven in other uses, shock testing revealed that the shock spectrum transmitted to the deployable exceeded allowable levels by a factor of three. Hence, an investigation of alternate pin arresting mechanisms was initiated.

Investigative Approach

The investigation proceeded in four steps:

(1) Formulation of pin arresting shock absorber design concepts.

(2) Formulation of an analytical model to describe the process.

(3) Static testing of candidate pin arresting mechanisms

(4) Pyrotechnic tests of candidate mechanisms.

All of the various concepts considered can be approximated by a simple spring mass second order system model. However, it became rapidly obvious that accurate information on the various parameters in the model was not available, particularly the force-displacement time characteristic of the pyrotechnic squib when actuated. The model was useful, however, in conceptualizing pin arresting approaches, defining desired pin arresting characteristics, and identifying shock paths.

The initial design thrust was to use a linear absorber. However, since energy absorbed is proportional to the volume of material strained, it became obvious that geometric constraints would not allow the required volume. This led to the investigation of non-linear absorbers.

The selected design, as shown in Figure 2, consists of a soft aluminum tube with a lead insert which is readily adaptable to a standard pin puller housing. The output shaft of the combustion chamber piston impacts the lead insert following release. The lead is extruded past the shaft end while the aluminum tube is being stretched. The four inch long tube (approximately one half inch in diameter) is stretched about 0.4 inch. Since this elongation is far beyond the elastic limits of aluminum, a distinct non-linear force versus deflection curve is generated. The tube cross section area is sized to absorb the pin impact energy well before fracture would occur.

Test Results

Static testing was performed to determine the force-displacement and energy capacity characteristics of several candidate absorbers. Since the approximate pin energy was known from earlier tests, this allowed the geometry of each device to be scaled to absorb the pin energy within existing displacement constraints. Examples of the characteristics for the ferrule design and for the stretch tube design are given in Figure 3. The ferrule design produced a fast rising force level at the end of travel (to absorb the required energy) as the swaging process is completed. Alternate ferrule designs with greater material volume were considered but could not be accommodated within the geometric constraints of the existing release mechanism design. The stretch tube absorber design eliminates the high force at the end of travel, but still has a steep initial rise in the force-displacement curve. The lead insert, when properly sized, effectively eliminated the steep initial rise. This was later found to reduce the high frequency levels of the shock spectrum response.

Pyrotechnic tests were then performed to evaluate the performance of the prime candidate pin arresting mechanism designs. The tests were conducted using high frequency accelerometers to measure the transient shock response. A triad of accelerometers were mounted at both ends of the release mechanism, as shown in Figure 1. Accelerometer triad #1 essentially measured the shock at the pin puller while triad #2 measured the shock at the deployable. In all cases, the accelerometer transient shock data was processed through a spectral analyzer to obtain a shock response spectrum for comparison to response requirements.

It should be noted that observation of the transient shock response verified that the high shock levels were indeed due to the pin impact shock and not due to the shock from the pyrotechnic squib firing. The shock response spectrum data includes all effects; however, the pyrotechnic firing contributes little to the overall levels observed.

Figure 4 shows the shock response spectrum for the original pin arresting ferrule design at both the pin puller location and the deployable location. Only the high shock direction (Z) is shown. Figure 4 also shows the same responses for the selected design. Table 1 presents a summary of various design approaches and the shock levels that were measured.

As can be seen from Figure 4, the original design had considerable shock response amplification from the pin puller to the deployable. This occurred even though there was a significant distance from the shock source to the deployable (which was intended to attenuate the response). The selected design was successful in reducing both the pin puller shock level and in reducing the amplification, resulting in a five-to-one reduction in the peak shock response at the deployable. Significant reduction was achieved across the complete frequency spectrum of 200 Hz to 10,000 Hz.

CONCLUDING REMARKS

A simple pin arresting mechanism has been designed which effectively reduces the resulting shock spectrum levels and is easily adaptable to various pin puller designs. The design is based on the elongation of material.which is an effective and predictable method of absorbing impact energy.

A design approach consisting of simple modeling of the arresting mechanism followed by static tests of the energy absorption characteristics prior to relatively expensive pyrotechnic shock testing has been shown to yield satisfactory results. Shaping of the static characteristics was effective in reducing the shock spectrum response levels at all frequencies.

Although this investigation has relied primarily on an empirical testing approach, further development of the dynamical shock model would likely lead to additional improvements and should be the subject of future investigations.

Table 1. Summary of Pyrotechnic Shock Test Results

Test No.			Shock Response Spectrum Peak (G's)		Shock Response Spectrum at 1000 Hz (G's)		Stop Stroke (in.)
			Pinpuller (#1 Z)	Deployable (#2 Z)	Pinpuller (#1 Z)	Deployable (#2 Z)	
1.	Original Design - Aluminum Ferrule 0.3 in. long		7500	18000	4400	4000	0.20
2.	Same as 1 - also split body with splice plate(a)		7800	7000	4400	3100	0.20
3.	Aluminum Stretch Tube Design:						
	Tube Area in.^{2}	Lead Pellet Length (in.)					
3a.	0.091	0.20	9800	10000	3700	1900	0.47
3b.	0.180	0.40	4600	8100	1900	3100	0.31
3c.	0.139	0.20	5000	5600	1000	2000	0.21
3d.(b)	0.121	0.20	3100	3400	1600	1000	0.41
4.	Same as 3d - also split body with splice plate(a)		3000	2500	2700	1100	0.45

(a) Release mechanism body split (approximately halfway between pin puller end and toggle bolt end) and remated with splice plate and rivets. This provides shock path attenuation between the pin pullers and the deployable.

(b) Selected design. Average of 4 tests.

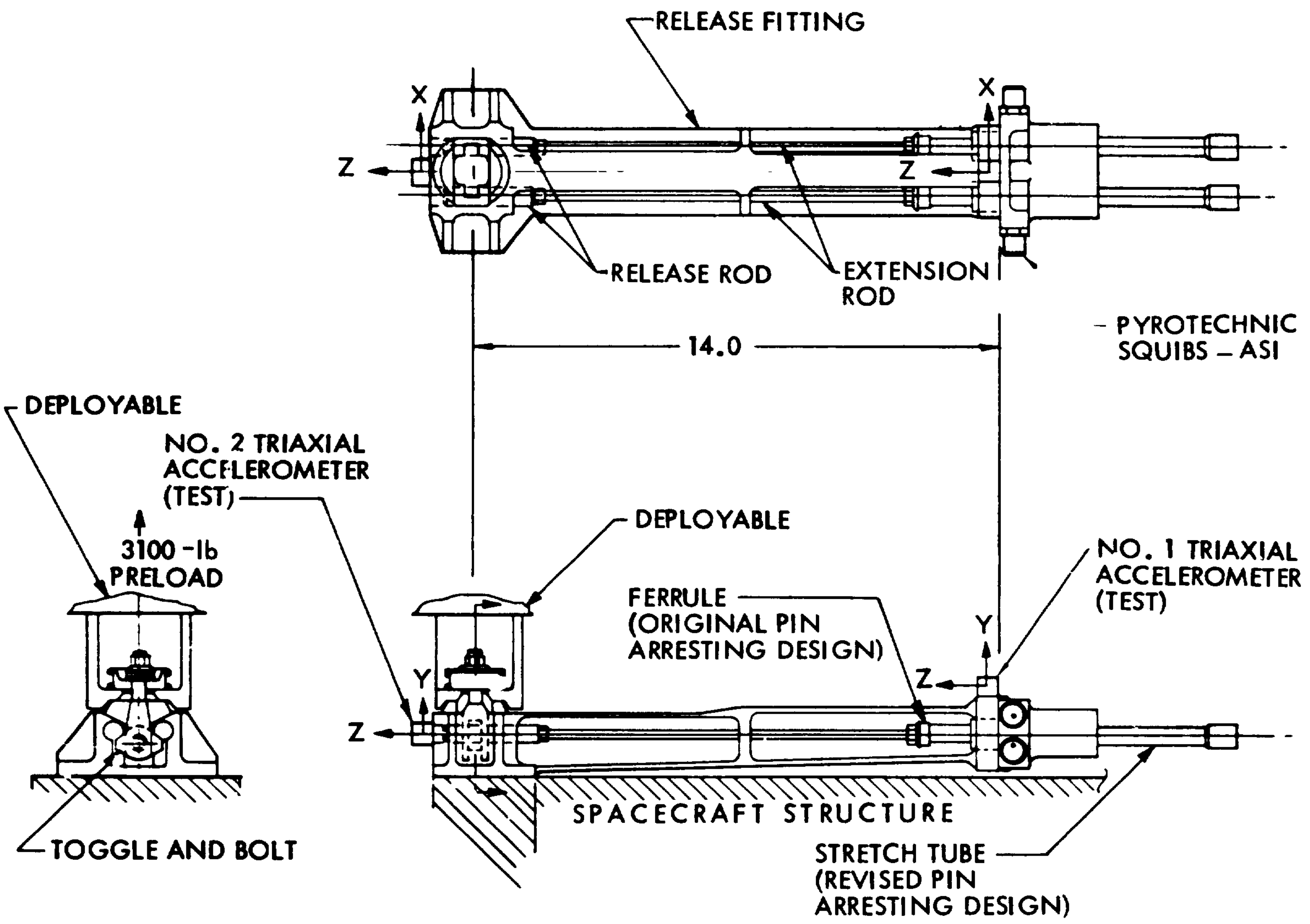


Figure 1. Release mechanism design

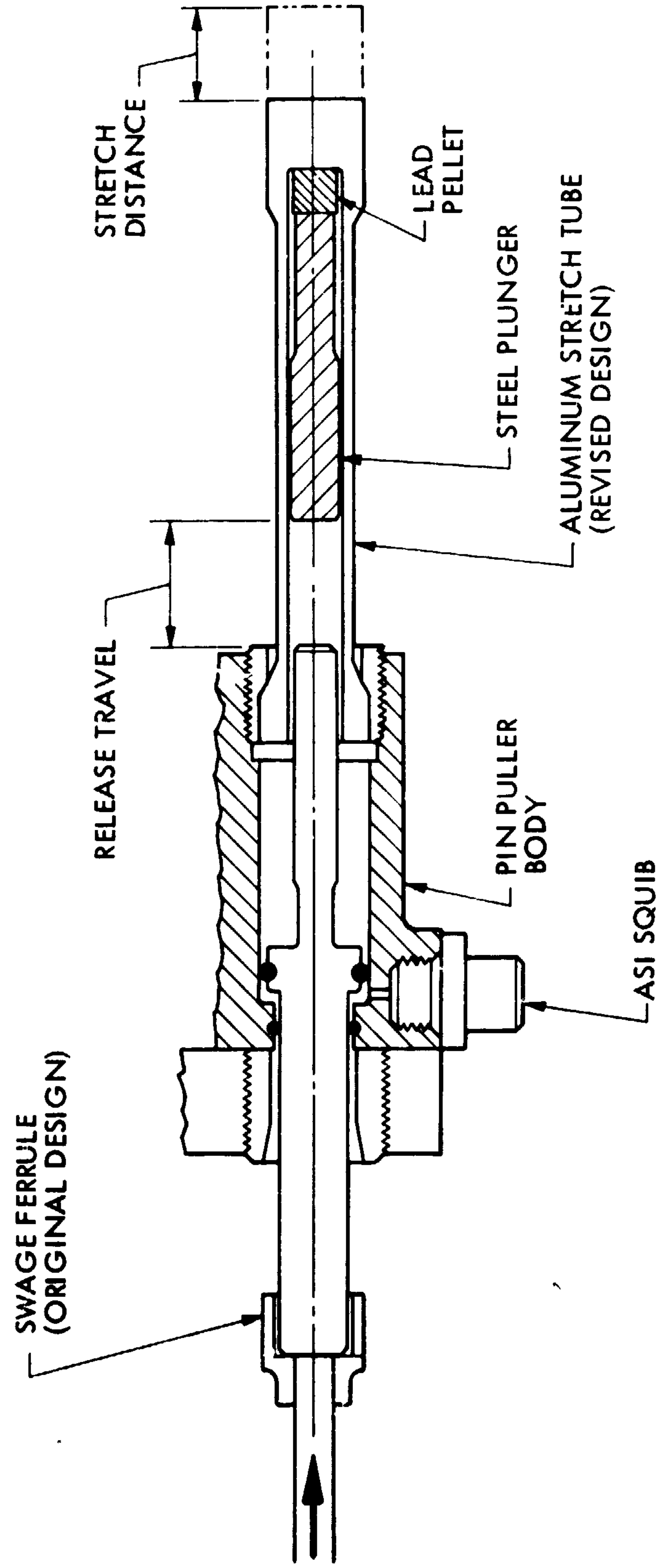
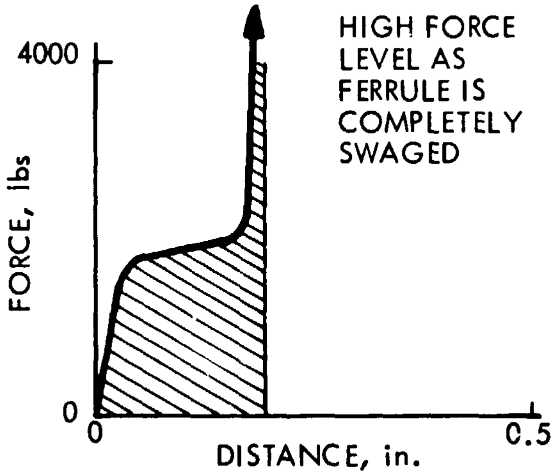
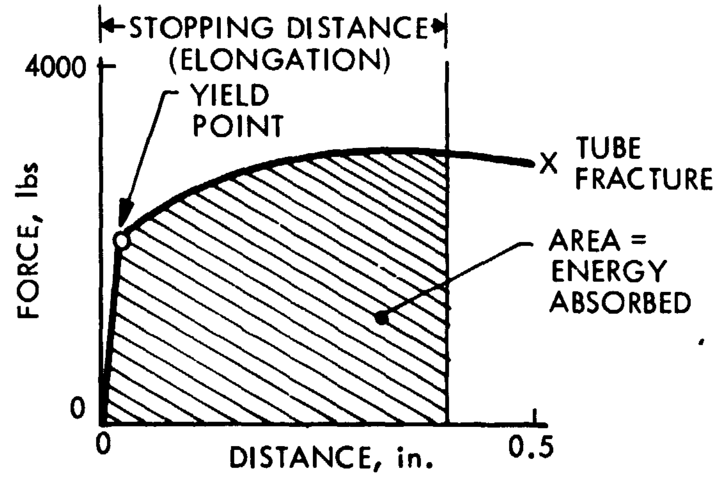


Figure 2. Details of pin arresting mechanism showing original (ferrule) and selected (stretch tube) designs

a. Characteristics of ferrule/swaging collar design



b. Characteristic of stretch tube design (high elongation material)



c. Characteristic of stretch tube design with addition of lead pellet (low modulus material) to reduce initial steep force rise.

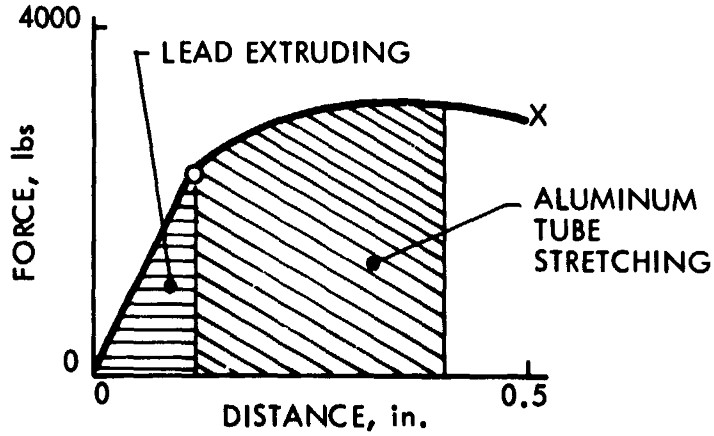


Fig. 3. Typical static force-displacement characteristics of absorber designs

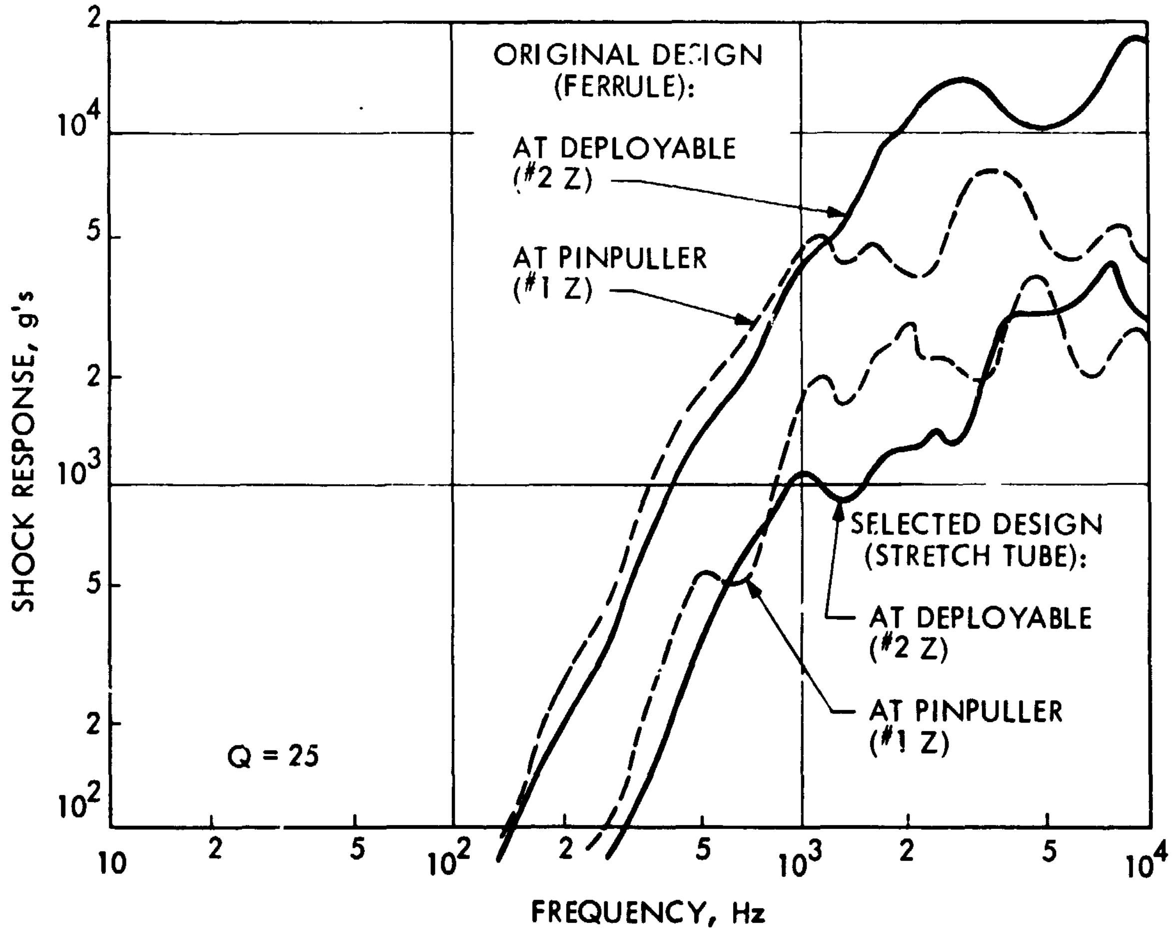


Fig. 4. Shock spectral response for original design and selected design