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Ball-Lock-Bolt Separation System

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This paper describes the ball-lock-bolt separation system, which was developed for aerospace applications that require a low-shock, controlled-release, nonfragmenting fastener. Different versions of the system are discussed, including manifolded arrangements and single-point release types, both of which have been successfully flown in space.

. Introduction

The total system requirements for the ball-lock-bolt eparation system may include any or all of the followng constraints:

(1) The separation function must be "soft," imparting no impulse to the separating vehicle.

(2) The system must completely contain all pyrotechnic gases, particles, and contamination.

(3) The system must have high strength in tension and shear for structural load requirements.

(4) Actuation must be manual for ease of assembly and handling.

(5) The flight system must be capable of being tested for function during ground handling operations.

(6) Flight safety must be maintained by providing an inert system until final installation of the pyrotechnics.

II. Principle of Operation

The ball-lock-bolt separation concept provides a basic mechanism of simple design with a proven history of satisfactory performance. Figure 1 depicts the basic elements of the mechanism. These are the bolt body, the actuation spool, the restraining collar, and the release balls. The collar and the bolt disengage when the actuation spool is displaced such that its reduced diameter allows the ball to retract below the outer diameter of the bolt. The only energy released as a result of the separation action is the strain energy involved in preloading or torquing the bolt on installation.

A kinematic study of the release action of a ball-lock-bolt is shown in Fig. 2. This study presents four loading conditions encountered during the release action.

A. Static Loads

Figure 2a depicts the condition of the system under a static tensile load F. All forces through the ball act

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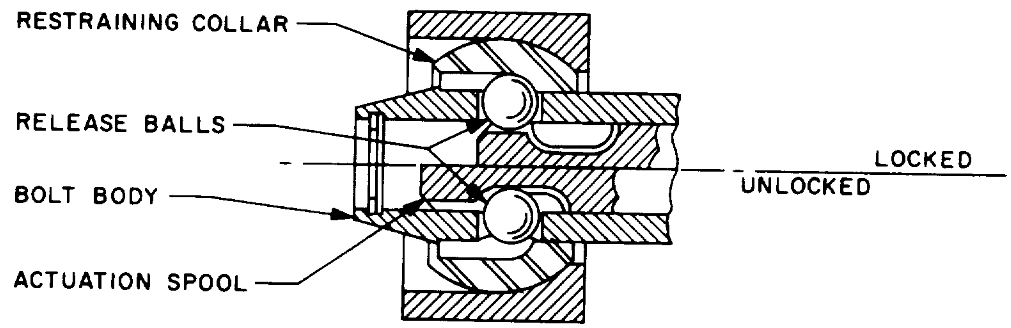


Fig. 1. Basic elements of the ball-lock-bolt mechanism

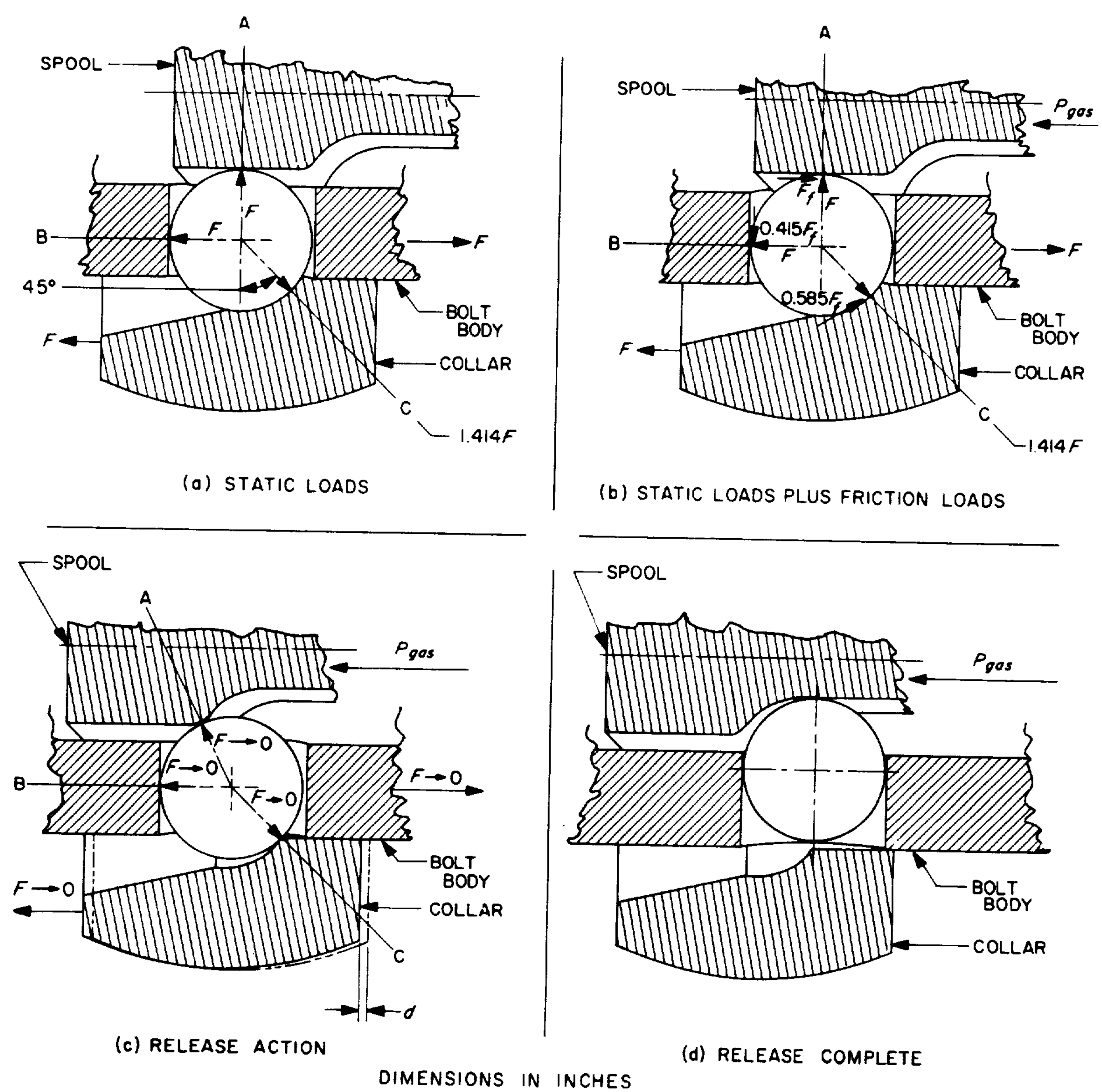


Fig. 2. Kinematic study of the ball-lock-bolt release action, showing four loading conditions

normal to the surface of the ball. Assuming a 45-deg contact angle with the collar, the reactions at points A and B are equal to the applied force F, and the reaction at C equals $1.414 \times F$. This loading condition may be maintained indefinitely at levels below the proof loads shown on Fig. 3.

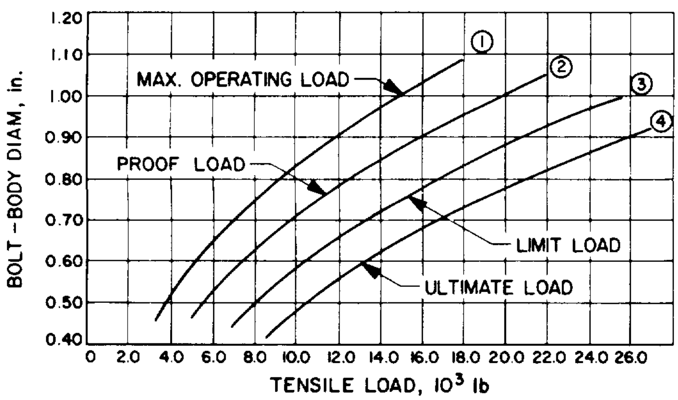


Fig. 3. Load capacity of a properly proportioned ball-lock-bolt mechanism

B. Static Loads Plus Friction Loads

Figure 2b depicts the condition of the preloaded system at the instant of first pool motion under gas pressure P_{gas}. The full breakaway static friction force F_f is developed only at point A. This sliding friction force tends to produce rotation of the ball, which is counteracted by static friction forces at B and C. It is noted that the friction reaction at C is in the direction to oppose motion of the collar.

C. Release Action

Figure 2c depicts the condition of the system as the ball has started to retract within the bolt body and he system preload has dropped to zero. The system preoad is represented by the distance denoted as d, which s equal to the total elastic strain of the system under preload. At this point, no forces are acting on the ball. t is noted that the motion of the collar at this point is lue to the elastic spring-back of the restrained system, ot to any release action attributable to the bolt.

D. Release Complete

Figure 2d depicts the final condition of the system as e spool has moved sufficiently to permit the ball to rop below the outer diameter of the bolt. The collar now completely free to disengage and separate from e parent vehicle.

III. Tensile Strength

The tensile strength of a ball-lock-bolt mechanism is a function of the number of balls utilized and their geometric arrangement. The load capacity of a properly proportioned ball-lock bolt is depicted in Fig. 3. The four curves represent the various loading conditions as a function of bolt-body diameter versus tensile load. These curves represent the results of actual tests and may be considered typical for a well-proportioned bolt.

Curve 1 represents the maximum operating load, defined as the maximum load at which the device may be released without degradation. It is recommended that the bolt be operated at as low a tensile load as the application will allow.

Curve 2 is the proof load or maximum structural working load. This load is applied to each bolt as an individual acceptance test. Any subsequent loading within this limit may be applied repeatedly without plastic deformation taking place.

Curve 3 represents the limit load, defined as the load which will cause a minimum deformation and which, after being removed, would have produced sufficient yield to reduce the initial preload to zero. However, the bolt will still maintain that applied load, after which successful release can be accomplished.

Curve 4 represents the ultimate load, defined as the load at which sufficient deformation has taken place to prevent clean separation. The bolt, however, will be structurally intact. The point at which tensile failure or fracture will occur is somewhat above this curve; for example, the 0.550-in. diameter bolt shown in Fig. 1 has been loaded to destruction in the 14,000- to 15,000-lb range.

IV. Applications

Figure 4 depicts typical separation-system bolts, which were flown on the MK11, 11A, and 12 reentry vehicles, and Fig. 5 shows several general arrangements for the associated gas generator and tubing manifold systems. The manifolding may take the form of pneumatic tubing, a confined detonating fuse, or an electrical network distribution.

The pneumatic-tubing arrangements shown in Fig. 5 are usually applied either when insufficient electrical

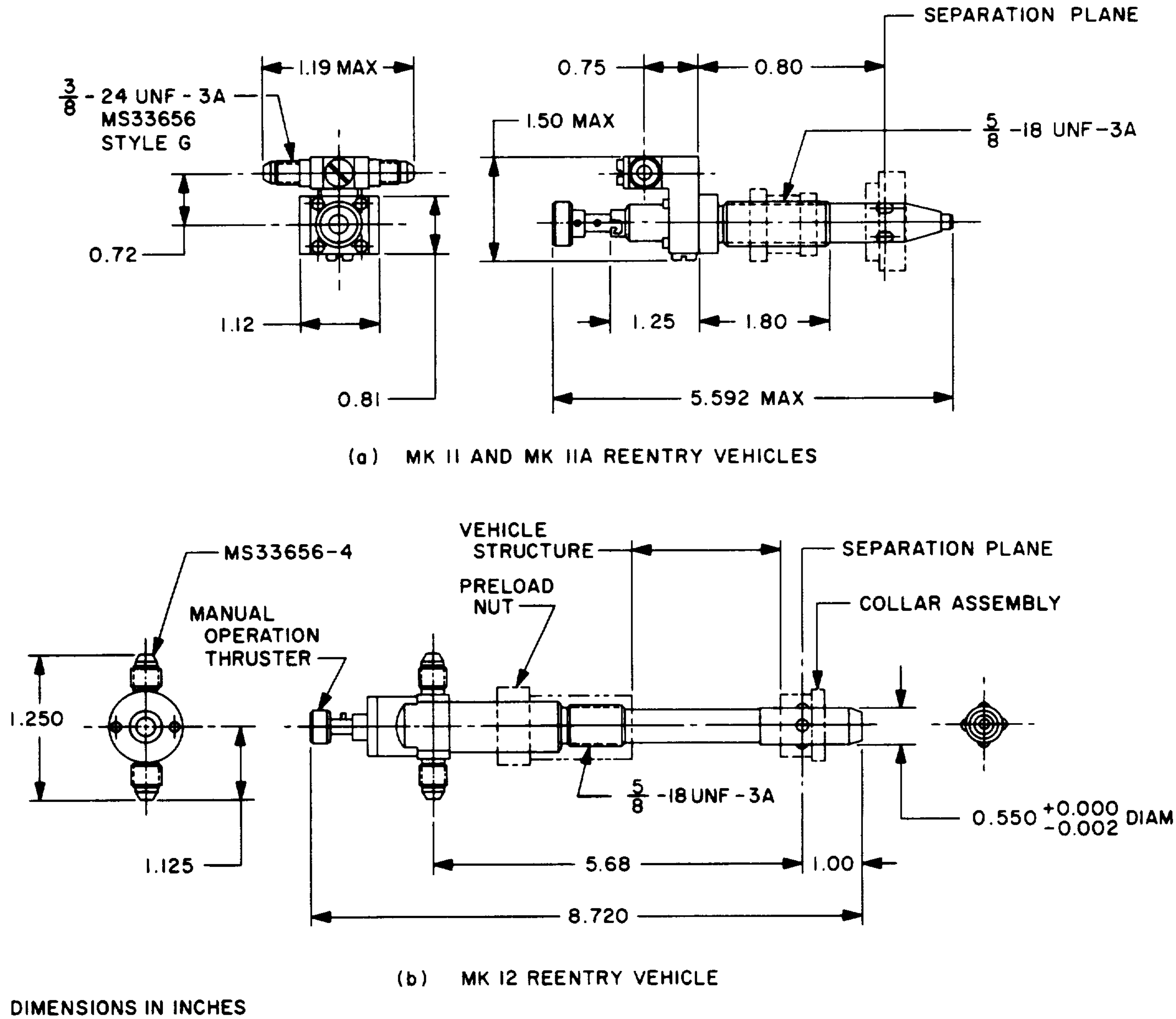


Fig. 4. Typical separation-system bolts

power is available or the number of circuits is at a minimum. Two electrically initiated gas generators, either of which will operate the separation system, with the appropriate tubing manifold, constitute the usual arrangement, as shown in Fig. 5a and b.

For manifolded systems requiring release under high preload conditions or high active-load conditions, the recommended arrangement is that shown in Fig. 5c, in which three gas generators are available but any two will successfully operate the release system. This scheme would reduce the peak pressure required of the full operating system. Another possible source of manifold pressure is a cold-gas storage bottle with a single- or dual-cartridge valve. In cases where electrical energy is abundant, each separation bolt can incorporate dual cartridges.

Should higher load levels than those depicted in Fig. 3 be required, a second row of balls may be added rather than increase the bolt-body diameter. The capacity of a tandem-row ball-lock bolt will be approximately 190% of the curves shown. However, Curve 1, representing the maximum operating load, would remain essentially unchanged.

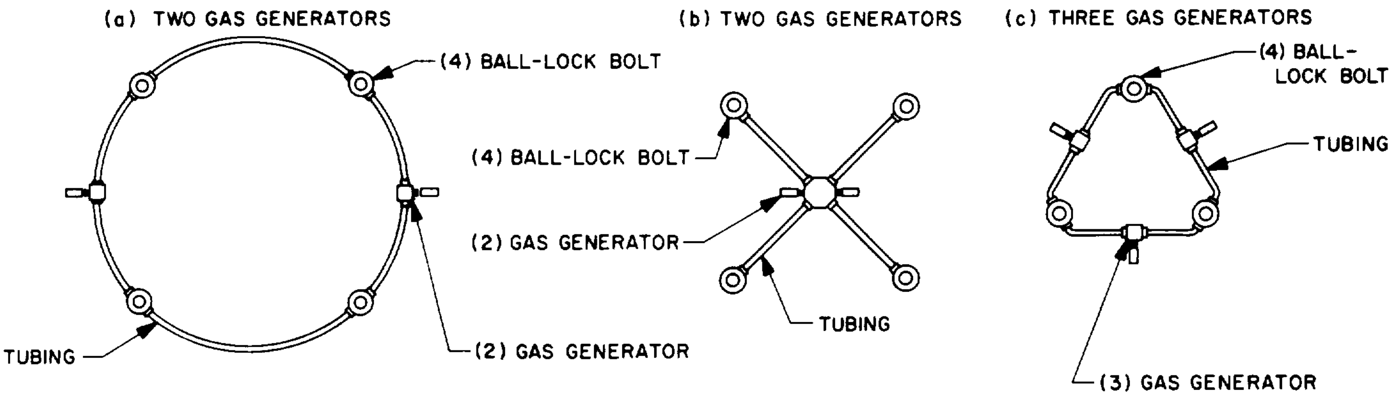


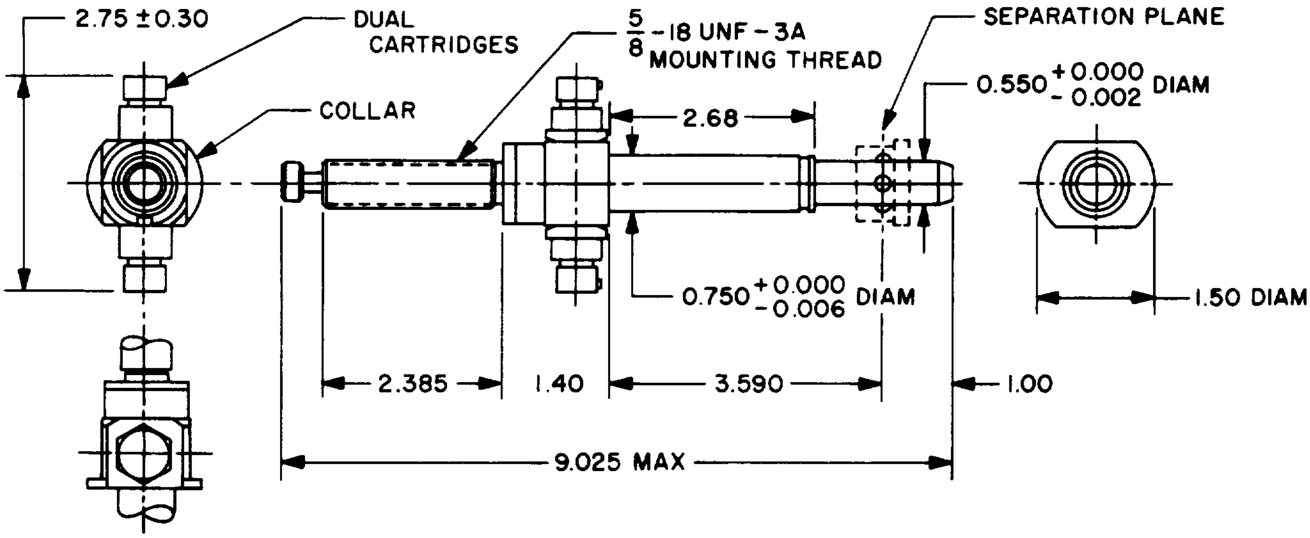
Fig. 5. Three general arrangements for gas generator and tubing manifold systems

V. Single-Point Release Applications

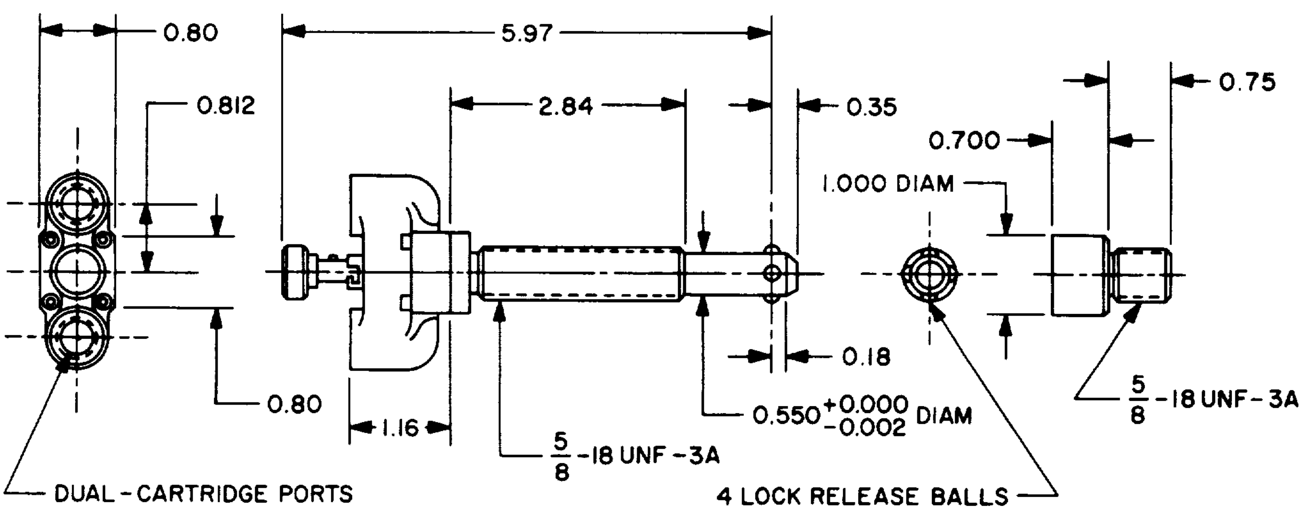
A number of versions of the ball-lock bolt have used single-point restraint. Figure 6 depicts two typical single-point release bolts, both of which have performed successfully in space. In these applications, multiple nuts are used in the long threaded portion to retain the bolt after separation, and the attitude-control-package release bolt doubles as an ejection-spring guide. This arrangement, in which the bolts are released by direct-fired dual cartridges, has proved very satisfactory. However, for systems requiring very high preloads, the peak energy of the dual cartridges produces an excess-energy problem. For high preloads, in the range of 5,000 lb, repeated tests may be conducted on a single bolt only at the single-cartridge pressure level. Reuse after dual-cartridge operation is not recommended.

VI. Conclusion

The ball-lock-bolt separation system offers the designer a wide range of potential applications for soft separation functions. Its application for quick-release systems is limited only by the ingenuity and imagination of the systems designer. For example, a ball-lock bolt could both release and retract with the pyrotechnic energy of the gas generator system, providing a clean separation plane. Conversely, separation thrust could be provided by continuing the stroke of the actuation spool, thus utilizing the manifold energy for separation force. It is possible to hydraulically interconnect a system of bolts whereby simultaneous release and thrust are guaranteed. Since the test hardware for any new system could be used repeatedly, these systems could be developed in a minimum time with a minimum cost.



(a) ATTITUDE CONTROL PACKAGE RELEASE BOLT



(b) BIOSATELLITE RELEASE BOLT

DIMENSIONS IN INCHES

Fig. 6. Two typical single-point release bolts