SPACE SHUTTLE ORBITER SEPARATION BOLTS

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ABSTRACT

Evolution of the Space Shuttle from previous spacecraft systems dictated growth and innovative design of previously standard ordnance devices. Initially, one bolt design was programmed for both 747 and External Tank application. However, during development and subsequent analyses, two distinct design evolved. The unique requirements of both bolts include: high combined loading, redundant initiation, flush separation plane, self-righting and shank attenuation. Of particular interest are the test methods, problem areas and use of subscale models which demonstrated feasibility at an early phase in the program. The techniques incorporated in the shuttle orbiter bolts are applicable to other mechanisms.

INTRODUCTION

The Space Shuttle Orbiter Separation Bolts are located as shown in Figure 1. The Orbiter/747 attachment system used for Approach and Landing Tests (ALT Bolt) has one bolt forward, three each side aft, and the Orbiter/External Tank (Shear Bolt) uses one bolt forward and one frangible nut each side aft. Development of both bolts followed similar sequences with much of the experience gained during ALT Bolt development and testing applied to the Shear Bolt.

The sequence of development testing for both bolts consisted of the following:

- Cartridge Load Sizing
- Separation Section Sizing
- Margins Demonstration
- Piston Flushness Verification
- Centering Mechanism Operation
- Environmental Exposure

After development, the bolts are subjected to a rigorous qualification program prior to flight certification.

ALT BOLT

The ALT Bolt, illustrated in Figure 2, has mechanical and pyrotechnic redundancy. Either cartridge will cause separation of the shank at the separation plane. The housing adapter and secondary piston are 4340 steel, nickel plated; the primary piston and shank were specified to be Inconel 718, all components are heat treated to 180 - 200 KSI. Load capacity is 141,630 lbs. tension, 11,168 lbs shear and 85,757 in-lb. in bending. The two pressure chambers are isolated such that either piston will cause the shank to separate in a tensile failure.

Separation was not a problem with the upper cartridge due to direct impengement of the cartridge output on the head of the secondary piston. The side cartridge port design initially offered sufficient gas flow restriction and pressure decay to not permit separation. The side port was subsequently enlarged to an eliptical shaped hole. Because the new shape and location of the port did not permit conventional machining, proting was accomplished using electro-discharge machining.

The second problem which casued a failure to separate was traced to the pressure cartridge. The cartridge load and subsequent consolidation pressure had been increased after several development tests. Closed bomb tests revealed that the additional loading pressure increased the pyrotechnic density such that the burn rate was reduced. The loading pressure was reduced and successfully verified by functioning the bolt with a single lower 80% loaded cartridge at low temperature.

The third corrective action was the use of a shrink fit collar at the base of the bolt housing. When the bolt was functioned with dual simultaneous cartridges, the residual energy of the primary piston slamming against the shank caused the shank and housing threads to yield. As deliverable hardware was complete at this time, a shrink fit collar was added on the outside of the housing which increased the hoop strength eliminating any yield of the housing.

A total of 35 ALT Bolts were expended during the five Shuttle Approach and Landing Tests recently completed. Thirty-four bolts were successfully tested in qualification and seventeen were consumed in development.

SHEAR BOLT

Analysis of the post-separation plane interface indicated that the .1 inch wide by .2 inch deep groove of the ALT Bolt was not tolerable due to aerodynamic boundry layer disturbance Additionally, to enhance reliability, a single piston, dual cartridge bolt was configured as shown in Figure 3. Shearing of the bolt with a punch and die technique allows the piston to fill the hole made by the separated end of the shank. Several sub-scale and full-scale specimens were sheared under static and dynamic loading conditions to confirm repeatability of a straight cylindrical shear plane.

The Shear Bolt components are fabricated from Inconel 718 forgings. The primary piston and shank material was specified due to flight environments, and the housing for compatibility and to eliminate the need for additional processing. Sizing of the break section and ultimate load testing was accomplished on a specially designed test fixture which applied tension and shear loads simultaneously. Load capability of the Shear Bolt is 166,740 lbs. tension and 127,400 lbs. shear applied simultaneously.

Initial concerns for the Shear Bolt were the spread of margins, (single 85%, dual 120% loaded cartridges) and piston flushness (plus/minus .010 inch). After several successful development tests, a failure to separate occurred. Investigation revealed a possible mechanical interference of the bolt housing and shank which increased the initial free volume. The design interference was corrected and the free volume reduced. The design change was verified by successful separations with single 80% and dual 130% loaded cartridges.

Experience from the shank/housing thread problem on the ALT Bolt was utilized in the Shear Bolt by increasing the cross section of the piston attenuation skirt and incorporating a buttress thread to minimize radial loads.

Primary piston attenuation and flushness within .020 inch at end of stroke was a difficult requirement. Due to the margin requirement with a single cartridge, the piston has considerable energy after separation with dual cartridges. The piston has a skirt which flanges outward upon inpact with the shank, slowing the piston and absorbing residual energy. Final piston position is determined by deformation of the mating surfaces. Final dimensions were determined by emperically tuning each shot until acceptable and repeatable flushness was achieved.

PRESSURE CARTRIDGES

The pressure cartridge for the two bolts are almost identical (See Figure 4), except for overall size to accommodate different pyrotechnic loads. The cartridges are of modular design utilizing the NASA STANDARD INITIATOR (NSI-1). Construction and materials are standard for spacecraft applications. The output charge is SOS 109, selected for its stability and previous experience. The cartridges produce pressures up to 50,000 PSI in the bolt initial volume. The pressure cartridges are fabricated from homogeneous lots of materials and subjected to hydrostatic, electrical, leakage, X and N-Ray inspection. Approximately 10% of each lot is functioned in a closed bomb for acceptable and uniform pressure/time characteristics.

CENTERING MECHANISM

The forward Separation Bolts are installed in a spherical bearing, Figure 5, which provides angular displacement while installed. After separation the centering mechanism must re-align the bolt, making the piston end flush with the external surface of the spacecraft. The envelope for the centering mechanism made the use of high strength alloys mandatory.

In order to achieve forces in the plungers which prevent displacement under accelerations, Cobalt Alloy was selected for the spring wire. This material has a tensile strength of 300,000 psi.

SHANK ATTENUATOR

The separated bolt shank has considerable residual energy when the bolt is functioned with two cartridges. In the Orbiter/747 configuration the bolt shanks had to be easily removable and cause no permanent damage to the structure. A ring of 6061-T651 aluminum was designed to be extruded between the shank and the mating structure. The deformation of the ring absorbed most of the energy and the difference in materials permitted easy removal of the shank. Although not required for the External Tank, the attenuator was retained in the design to eliminate the possibility of any re-bound of the shank. The attenuator is shown in Figure 6.

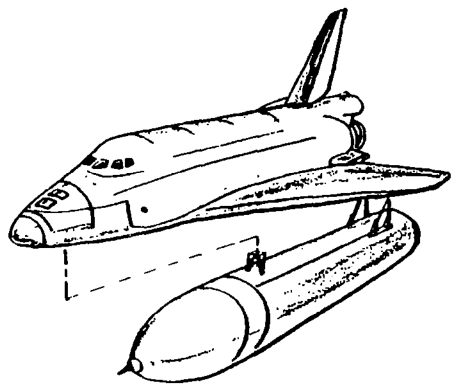
CONCLUDING REMARKS

Although the principle of cartridge actuated piston type bolts has been used for spacecraft applications for some time, the Space Shuttle Orbiter Separation Bolts represent a growth in loads, operating pressures, material strengths and mechanical features which have never previously been combined into operational devices.

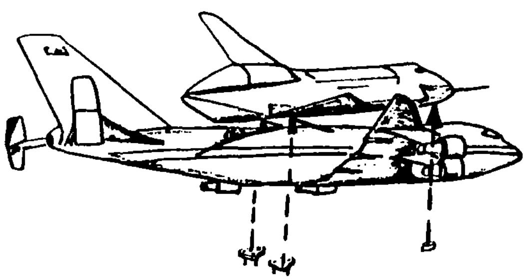
To ensure continued reliability, in addition to testing conducted during development and qualification of the initial flight lots; subsequent hardware will maintain stringent process control, extensive use of non-destructive test techniques and destructive sample testing.

ACKNOWLEDGEMENTS

Acknowledgements are given to NASA, who conceived the Space Shuttle concept which originated the need for the Orbiter Separation Bolts and Rockwell International/Space Division, who generated the detailed bolt functional requirements.



1- SHEAR BOLT



7- ALT BOLTS

FIGURE 1

ORBITER ATTACHMENTS

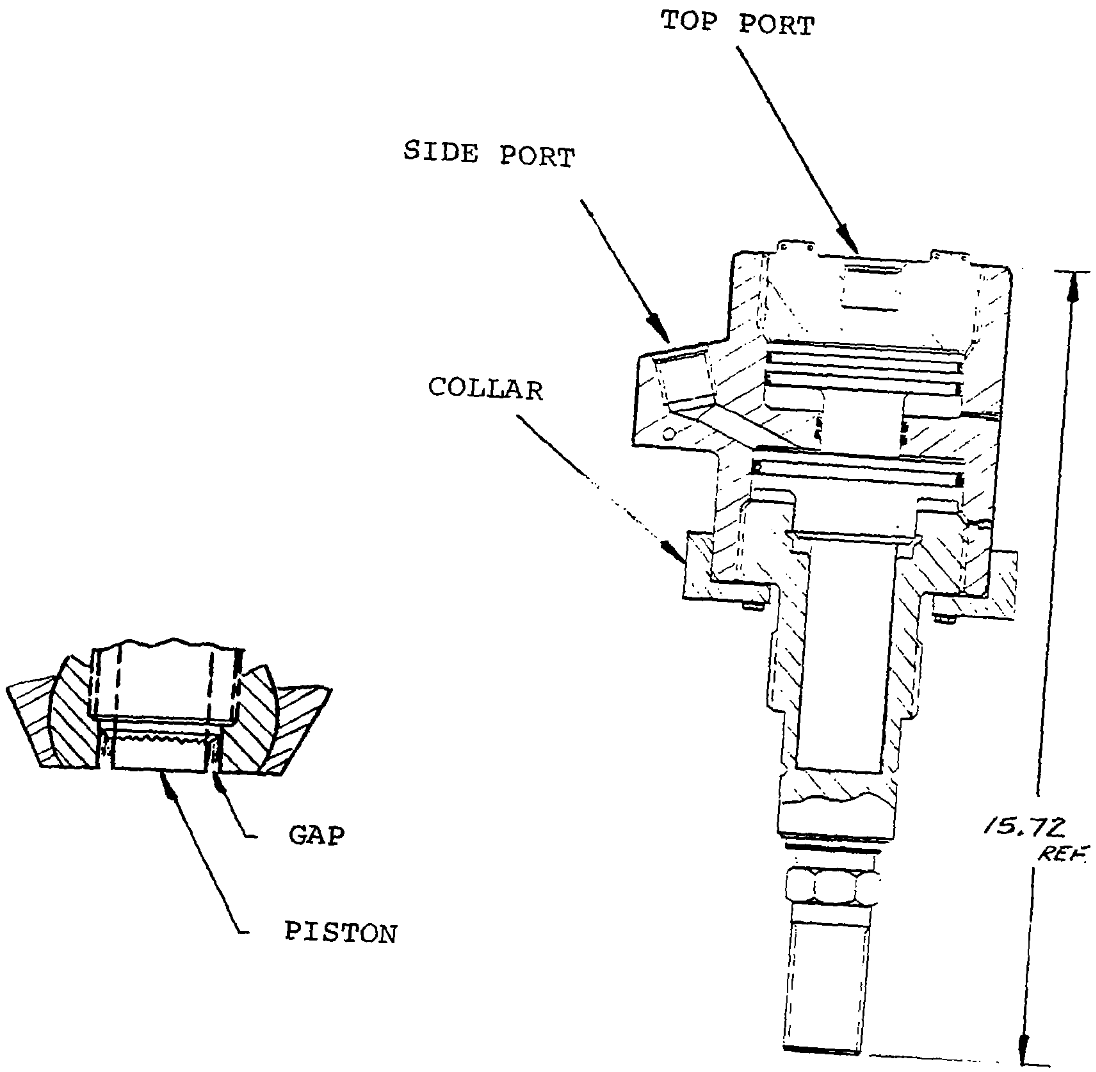


FIGURE 2

ALT BOLT

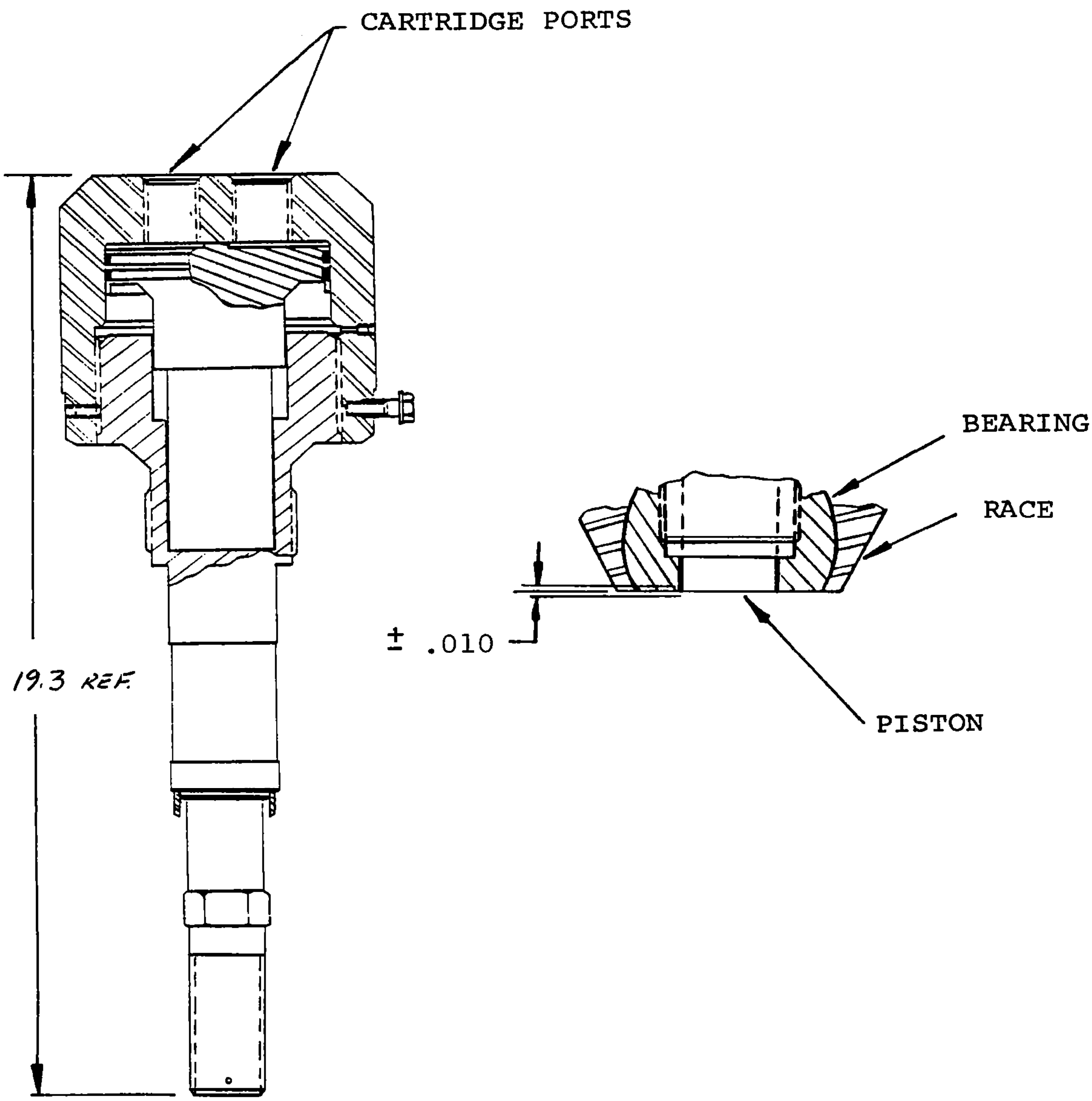


FIGURE 3

SHEAR BOLT

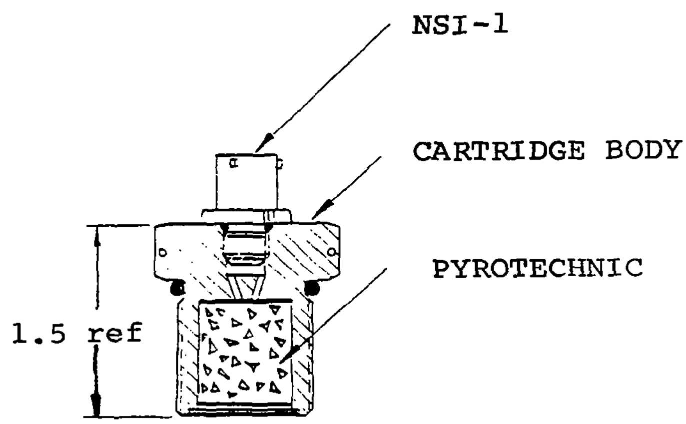


FIGURE 4 - PRESSURE CARTRIDGE

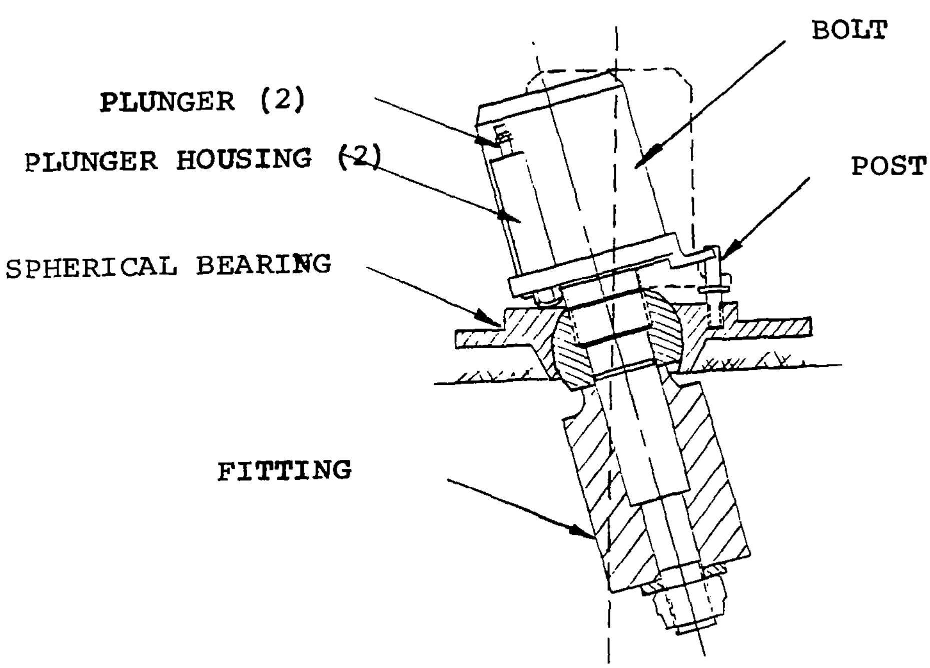


FIGURE 5 - CENTERING MECHANISM

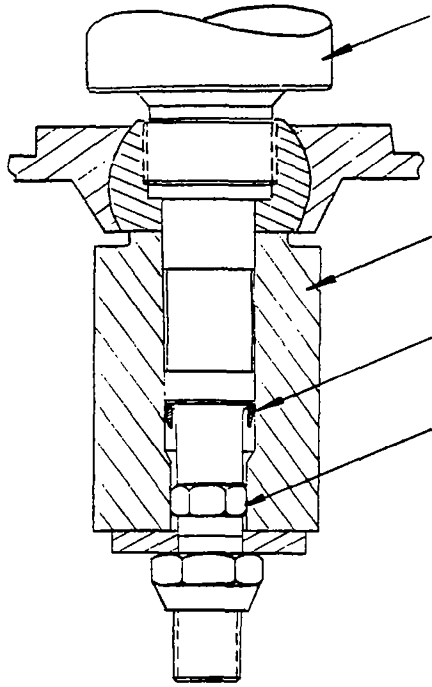


FIGURE 6 - ATTENUATOR