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SPACE SHUTTLE HOLDDOWN POST BLAST SHIELD

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ABSTRACT

This paper describes the original and subsequent designs of the Solid Rocket Booster/Holddown Post blast shield assemblies and their associated hardware. It presents the major problems encountered during their early use in the Space Shuttle Program, during the Return-to-Flight Modification Phase, and during their fabrication and validation testing phases.

The actions taken to correct the problems are discussed, along with the various concepts now being considered to increase the useful life of the blast shield.

INTRODUCTION

The exhaust plume of the SRB's used during Space Shuttle launches consists of hot gases and aluminum oxide particles and has the effect of a huge sandblaster. Launch hardware such as the Holddown Post System, which serves as a support stand and restrains the Space Shuttle System during Space Shuttle main engine thrust buildup, sustains extensive damage during launch. If unprotected, the Solid Rocket Booster (SRB) aft skirt shoes and their mating spherical bearings are rendered useless after each launch and must be scrapped. Then there were blast shields....

The blast shield was conceived to prevent loss of launch hardware. In fact, current launch hardware cost comparisons estimate that the use of at least four blast shields saves the program approximately $250,000 per launch.

The blast shield is a mechanism that is attached to the holddown post with mount brackets which also act as hinges (see figure 1). The shield rests against the fragment catcher of the frangible nut prior to launch. It is spring loaded, and during lift-off of the Space Shuttle, the front edge (skid plate) "cams off" the fragment catcher. This action increases the spring tension which causes the blast shields to close after separation from the SRB aft skirt. As its name implies, it shields the shoe, the top of the holddown post, and the spherical bearing from the hostile environment of the SRB's exhaust plume.

Because of the northerly drift angle of the Space Shuttle during lift-off, the north holddown posts (numbers 3, 4, 7, and 8) sustain the majority of the blast damage. Consequently, blast shields are installed only on these posts (see figure 2).

ORIGINAL DESIGN

The original design of the blast shield consists of the following major components:

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a. Hood. The hood is of hip-roof-shaped construction and is made of ASTM A36 steel plates. It has longitudinal and lateral stiffeners. The hood also has two hinge clevis mounts incorporated with the longitudinal stiffeners. The plates are pre-drilled for the hinge shaft. The hood of the blast shield closes over the holddown post to protect it and its associated hardware from launch blast.

b. Latch. Latch assemblies are located inside the clevis mounts and above the hinge shaft (left and right side). They prevent the hood from reopening due to back pressure of the exhaust blast. The latches are spring loaded so that pressure is applied towards the hinge brackets as the hood closes.

c. Hinge Shaft. The hinge shaft is made from ASTM A490 bolt material and supports the hood and the main torsion springs that close the hood. Spring stops are installed on both ends of the shaft.

d. Shaft Locking Pins. The shaft locking pins (two per blast shield) are made of drill rod material. These pins lock the shaft to the mount brackets after the springs have been armed. The pins are inserted through holes in the mount brackets, which are positioned at 45 degrees. The top ends of the pins protrude out of the mount brackets by 25 millimeters (1 inch) and are held in place by cotter pins.

e. Mount Brackets. The mount brackets are weldments (two per blast shield) made from ASTM A514 steel that are bolted to the holddown post on the side away from the SRB's. They are used to attach the blast shield to the holddown post, and also serve as hinges.

f. Main Torsion Springs. The torsion springs (two each) are made from ASTM A229 music wire and provide the energy to close the blast shield. One leg is longer than the other. The longer leg is turned 10 degrees from the parallel axis.

g. Skid Plate. The skid plate is mounted on the front edge of the blast shield with three hex head cap screws and contacts both the fragment catcher and the SRB aft skirt, which are made of Inconel and aluminum, respectively. It serves as a buffer between the fragment catcher and the SRB aft skirt and, to prevent contact damage, is made of 5086-H32 aluminum plate.

h. Spring Stops. The spring stops are made of ASTM A36 steel and are located near the ends of the hinge shaft. They are L-shaped and are held in position by flats on the shaft ends and by spring pins.

i. Shaft Support Lugs. The shaft support lugs are located on each side of the blast shield near the shaft ends. They support the shaft in case of excessive bending loads and provide an attachment point for the spring arming tool and shaft blast covers.

The lugs are made of ASTM A36 steel plate which is welded to the side of the blast shield in the vertical position. A hole at the bottom accommodates the shaft ends. Two tapped holes located just above the shaft hole serve as attachment points for the arming tool and the shaft blast covers.

j. Shaft Blast Covers. Also made from ASTM A36 steel, the shaft blast covers protect the shaft ends. They are attached to the shaft support lugs with two self-locking screws.

PROBLEMS ASSOCIATED WITH THE ORIGINAL DESIGN

The early versions of the blast shields failed to close during two launches prior to Space Transportation System (STS) mission 33 (51-L) (Challenger). These failures resulted in debris and raised concerns that the debris could become projectiles and damage flight hardware. For example:

a. On STS-26, launched July 29, 1985, post-launch inspection revealed "all blast shields came down; Blast shield on post #3 was slow in closing; skid plate missing; spherical bearing and shoe damaged; underside of blast shield has bad erosion damage...."

b. On STS-31, launched November 26, 1985, "Blast shields on post #'s 4 and 8 did not close. They were standing open at approximately 80 deg. after launch. All hardware was intact with no missing debris (parts). Shoes and bearings were eroded...."

The used blast shields were stored in several areas at the John F. Kennedy Space Center (KSC) and photographed for record purposes. Using these photos and reports published by blast shield inspection teams, areas of debris concern were identified. Specifically, in the failed-open blast shield condition, the following components are exposed to direct blast impingement with the following observed effects:

a. Shaft Locking Pins. The protruding part of the shaft locking pin was exposed to direct blast impingement. The cotter pins could not be located and are suspected of being vaporized or pulverized. The pins can easily slide back out of the mounting brackets and become projectiles.

b. Main Torsion Springs. The sandblasting effect of the SRB's has been observed to ablate the exposed (top) portion of the springs by more than 13 millimeters (0.50 inch), leaving 28 partial (horseshoe shaped) rings hanging on the main shaft.

c. Skid Plate. The aluminum skid plate could not be located and is suspected of being vaporized or possible pulverized by the sandblasting effect of the SRB exhaust.

d. Spring Stops. The spring stops became debris.

e. Shaft Support Lugs. None of the lugs ever detached from the blast shield during launch. However, in at least one post-launch inspection, some lugs were reported to be "barely hanging on to the blast shield."

Further, some of them could be detached manually from the blast shield without any effort.

f. Shaft Blast Covers. Although the shaft blast covers adequately protect the shaft ends, and have not been observed to sustain launch damage, they could become launch debris for the following reasons:

(1) They are attached to the shaft support lugs.

(2) They are outside the blast shield's envelope; therefore, they are fully exposed to the exhaust blast.

PRE STS-33 (51-L) MODIFICATION PHASE

Prior to the STS-33 mission, launched January 28, 1986, the blast shields were modified to ensure proper closure during launch, thereby reducing the possibility of blast shield parts becoming debris.

The major problems associated with the original design were weak main springs due to a low factor of safety on yield strength and the relaxation of the main springs, probably due to heat soak. In December 1985, the NASA KSC Design Support Contractor was directed to design a "kick spring" mechanism to aid the blast shield in closing during launch. The mechanism's design consisted primarily of a plunger, a compression spring, a housing, and 6-millimeter (0.25-inch) diameter retaining cables. The assembly was mounted between the mounting brackets behind the blast shield. The working principle was as follows: At some point during lift-off, the blast shield is intended to engage the plunger, which compresses the spring. As the aft skirt leaves the blast shield, the plunger provides the "extra kick" to close the blast shield. The rationale: The faster the blast shield closes, the less chance that debris will be generated.

POST STS-33 (51-L) FINDINGS

The post-launch report of STS-33 revealed that all blast shields closed normally with no damage to shoes and bearings. But the newly installed kick springs did not fare so well: The plungers, the springs, and their restraint cables were missing on all four holddown posts. One kick spring was found on the flat haunch of holddown post number 1, which is on the opposite side of holddown post number 3 (see figure 2). Two plungers were found at the north perimeter fence, approximately 400 meters (1/4 mile) away from the holddown post site! The cables were never found. These discoveries led to speculation that the kick springs may have contributed to the Challenger tragedy.

In a National Aeronautics and Space Administration (NASA) investigation report submitted in February 1986, the following facts were considered:

- The SRB plume flame is approximately 178 meters (600 feet) long.

- Two plungers were found at the north perimeter fence.

- The end cap was in place on one of the plungers, permitting metallurgical analysis. Analysis of an end cap indicated 0.30-miillimeter (0.012-inch) buildup of aluminum oxide around the sides.

- A full-duration exposure to flame will deposit approximately 0.74 mm (0.029 in.) coating.

- Therefore, 0.30 millimeter (0.012 inch)/0.74 millimeter (0.029 inch) = 41-percent exposure.

o Estimated height, h = 0.41 x 178 meters (600 feet) = 73 meters (246 feet).

o A preliminary assessment stated that the plungers came off after the vehicle was 200 to 300 feet up. Plungers were blown into the SRB flame trench and out to the perimeter fence.

A Film Analysis Report dated March 10, 1986, stated that, "The relatively short dwell time and rapid closure rate observed on all four blast shields suggests that the kick springs were in place and working until sometime after closure. However this cannot be confirmed by direct observation." Closures could not be determined due to flame obscuration. The report further stated that no direct impingement of SRB flame was evident in the vicinity of the kick springs throughout the observational interval (approximately 1.120 seconds), indicating that the cable restraints were still intact.

On the other hand, based on the known drift characteristics of the launch vehicle, it is probable that direct SRB flame impingement was of sufficient magnitude to burn off the cables after 1.120 seconds.

Both reports concluded that the kick spring assembly did not contribute to the Challenger tragedy. The incident did, however, increase concerns regarding holddown post and blast shield debris.

POST 51-L MODIFICATION (RETURN-TO-FLIGHT) PHASE

Between January 1987 and September 1988, the blast shield underwent an extensive modification program. Once again, the primary concern was strengthening the areas of the design contributing to the release of debris. Thus, redesign efforts focused on ensuring proper closure of the blast shields, eliminating the kick spring/plunger mechanism that proved so susceptible to launch blast, and modifying the design wherever possible to minimize blast impingement.

Accordingly, the blast shields were modified as follows (see figure 3):

a. Hood.

(1) The hinge clevises were opened up to prevent the hood from binding with the mounting brackets.

(2) The clevis hole diameter was increased and line bored to allow more clearance between the shaft and the holes.

(3) The latch shaft holes were enlarged to ensure proper operation of the latches and to preclude binding.

(4) The spring stop plates welded to the blast shield were properly located from the centerline of the main shaft to ensure that the springs engage the blast shield at the proper angles given the allowable tolerances.

b. Shaft Locking Pins. To eliminate the exposed cotter pins that held the locking pins in place, a new shaft locking pin was designed with a threaded end at the bottom. It was also shortened so that no part would be exposed to the exhaust blast.

c. Mount Bracket. The hinge holes in the original brackets did not align properly when mounted on the holddown post. This anomaly was concluded to be a contributing factor to blast shield failures because the shaft was binding with the hinge holes. Also, the addition of the spring blast covers reduced the clearance between the SRB shoes and the blast shield. Using the old brackets would have required the addition of shim plates between the holddown post and the brackets.

New one-piece bracket weldments made of AISI 4140 and heat treated to 1,034,000 kPa (150 ksi) to 1,241,000 kPa (180 ksi) were fabricated. The shim plate thickness was incorporated into the baseplate. The hinge holes on the vertical mounts were line bored.

d. Main Torsion Springs. To minimize debris, the main torsion spring envelope was reduced to allow full enclosure of the springs. Specifically, the mean outside coil diameter of the main torsion spring was reduced along with the number of coils.

Since the main torsion springs were suspected to be the major contributor to the blast shield's failure to close, they were modified further. The rationale for failure: Their constant exposure to high temperatures coupled with their prolonged pre-armed condition weakens them. Consequently, the main torsion springs were redesigned using ASTM A407 spring wire and increasing the wire diameter. The ASTM A407 spring wire has a higher tensile strength than the original ASTM A229 music wire: 1,550,000 kPa (225 ksi) versus 1,350,000 kPa (196 ksi), resulting in a higher factor of safety on yield, namely, 1.70 versus 1.01.

However, several concerns are inherent with the use of the new material. For example, KSC design specifications require a minimum factor of safety of 2 to 1. They further specify that no material used in Ground Support Equipment (GSE) shall have an ultimate tensile strength exceeding 1,241,000 kPa (180 ksi). The new material violated both specifications.

The concerns here were very real. The high tensile strength results in susceptibility to Stress Corrosion Cracking (SCC). These springs can stay on the launch pads for weeks in the armed (pre-loaded) position. The humid, salty atmosphere at KSC coupled with the loaded condition of the springs can hasten the effects of stress corrosion cracking.

On the other hand, the original springs had a very low factor of safety on yield (1.01) and were clearly inadequate for use on the blast shields, as evidenced by their failures. Designing springs with a factor of safety on yield of 2 would have required a bigger spring or the use of a higher strength material. Due to the limitations of the existing spring envelope, a bigger spring would have required a total redesign of the blast shields. Increasing the ultimate strength was equally unacceptable due to the increased chance of failure due to SCC.

Consequently, a waiver was obtained to allow the use of the new spring design with a factor of safety on yield of less than 2 and an ultimate tensile strength exceeding 1,241,000 kPa (180 ksi).

Interestingly, the use of square wire springs was considered. The section properties of a square wire spring increase the factor of safety and the strength, which would have eliminated the use of kick springs and/or additional springs while allowing a smaller spring envelope. Because it is not available as an off-the-shelf item and because of its relatively high cost, however, the use of square wire springs was rejected.

Therefore, the round wire springs were selected for use with the provision that they only be used for one launch. This policy was implemented to avoid failure due to heat soak or SCC caused by repeated use.

e. <u>Center Torsion Springs</u>. The kick spring assembly was replaced with center torsion springs made from AISI 5160 steel. Although the preferred choice was ASTM A401 steel wire, it was not available in 17.5 millimeters (0.69 inch) diameter. Two springs were installed in the middle section of the hinge or main shaft between the mounting clevises. The initial blast shield position is at 47 degrees; it engages the center torsion springs at approximately 67 to 70 degrees during lift-off.

The advantages of this design over the original design are that it consists of one-piece construction, it is easier to install, and it has a higher factor of safety (greater than 2 to 1 on yield).

f. <u>Spring Blast Cover Plates</u>. ASTM A36 steel plate spring blast covers were added for both the outboard and center torsion springs to prevent blast impingement. The blast cover plates were welded to the blast shield weldment. The outboard springs (or main springs) were fully encased while the center springs were provided with a bent plate for exhaust blast protection in case of blast shield failure in the open position. The center springs could not be fully enclosed due to the design of the spring stop.

g. <u>Skid Plate</u>. The basic profile of the skid plate was retained; however, the method of mounting changed. The original aluminum skid plate was mounted with three hex head bolts located on the front edge of the blast shield and was directly exposed to the exhaust blast. Two mounting plates were added to the modified skid plates to allow them to be bolted from the sides of the two longitudinal stiffeners, affording protection from direct exhaust blast impingement.

Although aluminum was used in the original design, post-launch inspections of blast shields soon revealed that aluminum components become debris. If the blast shields were to fail in the open position, the retaining bolts and the skid plate itself could be eroded and blasted away during launch. The concerns of skid plate damage to the SRB aft skirt and the fragment catcher, when weighed against the debris concerns associated with aluminum, left only one choice: The aluminum skid plates were replaced with steel skid plates.

h. Spring Stops. Because of the increased loads and change in dimensions of the new main springs, the spring stops were changed to AISI 4140. They were also tapered to provide clearance for the spring legs.

i. Shaft Support Lugs and Shaft End Blast Covers. The designs of the shaft support lugs and shaft end blast covers were simplified. The lugs were replaced with a spacer plate welded to the blast shield roof just above the shaft ends. The end cover plates were fabricated from steel plate and mounted with five socket head screws, the heads of which are recessed into the plate. These modifications streamlined the design of the blast shield by enclosing the end cover plates within the blast shield envelope.

VALIDATION TESTING

The exhaust plume of the SRB strikes the holddown post at T+1.6 seconds from SRB ignition. Consequently, one of the design requirements of the blast shield is that it must be in the closed position before the exhaust plume strikes the holddown post. Analysis predicted that, based on the center of gravity location, the drift angle of the Shuttle lift-off, the spring torque, and the surrounding pressure [1,034 kPa (150 psi)], the blast shield should close in 950 milliseconds. Because of recent modifications, and to verify analysis, testing and qualification were required for each blast shield.

Testing was conducted at KSC's Launch Equipment Test Facility (LETF) and consisted primarily of mounting the blast shield on a holddown post with the SRB shoe and spherical bearing installed. The blast shield was initially opened to a 47-degree angle, then wire rope cables and drop weights were attached to the blast shield. The weights were released using gaseous nitrogen (GN2) nuts. Release of the drop weights pulls the blast shield to its maximum opening angle (80 to 81 degrees) thereby simulating SRB lift-off (see figure 4). At the full-open point, the blast shield is released from the drop weight to close back onto the SRB shoe. Time is measured from the moment the drop weight is released to the moment the blast shield closes, resting on the SRB shoe.

This method of testing, however, did not accurately depict Shuttle lift-off. The release timing of the GN2 nuts varied somewhat, and the wire rope cables had a tendency to snag in the sheaves/pulleys during the closing cycle, thus delaying closure time.

Therefore, a Lift Off Simulator (LOS) Test Fixture was designed and built to more accurately simulate that period of time during lift-off when the blast shields are in contact with the SRB aft skirts (see figure 5). The fixture consists of the following major components/assemblies:

a. Winch and Cable System. A dropweight-operated winch-and-cable system is used to lift the aft skirt assembly, thereby simulating lift-off.

b. Holddown Post Assembly. The original LOS used an actual holddown post assembly, shoe, and spherical bearings. Although actual shoes and spherical bearings are still used, because of its relative scarcity, the holddown post has since been replaced with a facsimile.

c. Drop Weights. The drop weights and aft skirt assembly weight are set at a ratio to simulate 0.55 g lift-off acceleration.

d. GN2 Release Nuts. The drop weights are released by GN2 nuts.

e. Aft Skirt Assembly. In the aft skirt assembly, an actual support column and, because of its relatively high cost, a facsimile of the fragment catcher are used. The aft skirt assembly guide rails were set at 17 degrees from the vertical to simulate the drift angle during Shuttle lift-off. Since then, the drift angle has been revised to 13.5 degrees.

f. Instrumentation. The instrumentation system consists of the following components:

   (1) An accelerometer mounted on the blast shield for event tracking.

   (2) An electrical break switch mounted on the simulator guide panels for start time event signal.

   (3) An electrical crush switch mounted on the shoe for blast shield closure event signal.

   (4) A Linear Voltage Displacement Transducer (LVDT) or fishreel for data plots of displacement versus time.

   (5) Three high-speed cameras (located at the front, back, and side of the LOS).

g. Blast Shield. The actual blast shield being tested is mounted on the holddown post to rest on the aft skirt section.

The LOS was first used to validate the blast shields used in the STS-26R (Return-To-Flight) mission. The Interactive Laboratory System (ILS) indicated, in its observation of the LOS performance, that the LOS was rising at 0.60 g, faster than the 0.55-g acceleration indicated by camera data. The discrepancy was attributed to errors in reading the defined start times - the time is read from the ILS plots (instrumentation errors) then compared with camera data (viewing angle errors). However, since the discrepancy was negligible, data collected from blast shield drops were considered acceptable.

The first set of blast shields was then tested on the newly designed and built LOS. The results verified analysis data; specifically, the closure times averaged about 800 milliseconds and no interferences were encountered.

RETURN-TO-FLIGHT MODIFICATION PHASE COMPLICATIONS

Several problems were encountered during the Return-to-Flight blast shield modification program. For example:

a. Blast Shield Fabrication. The ten blast shields being modified were existing blast shields that had never been used for launch. These blast shields were measured and compared with the existing drawings, with an alarming discovery: No two blast shields were built the same, not one of the blast shields was built per the drawings, and the measurements taken exceeded allowable tolerances! Thus, the factor of quality control during fabrication entered the picture.

   Not much could be done about the differences in the dimensions of these blast shields, and few avenues existed to reduce the possibility of binding. Specifically:

   (1) The hinge shaft holes were line bored to a larger diameter.

   (2) Bushings then were press fitted in the enlarged holes then the bushings were line bored to the proper diameter with the correct amount of tolerance.

   (3) The clevis areas were widened by milling off about 1/8 inch from each side. The smallest gap allowed between the mount bracket and the clevis was 4.3 millimeters (0.17 inch).

b. Mount Brackets. The vertical portion of the mounting brackets interfered with the mating blast shields. Opening up the clevis mount of the blast shield eliminated the interference. This problem was just one of many which have resulted in the trial-and-error evolution of the mount brackets (see figure 6). Specifically, the brackets used during the 60-percent and 90-percent design phase were weldments. A fillet weld at the lower baseplate of the brackets was ground to provide room for the mounting bolts.

   The blast shield then underwent validation testing at KSC's Launch Equipment Test Facility (LETF). After testing, the blast shield was removed from the holddown post that was used as a test stand. One of the bottom base plates fell off . . . under a no-load condition! The cause was determined to be lack of weld fusion: a fillet weld was used instead of a bevel weld, as called for in the drawings. Grinding the fillet weld left about a 1.5-millimeter (0.06-inch) weld holding the foot to the vertical bracket. Additionally, several problems were associated with the use of welded 4140 parts, including a lack of established procedures and a lack of welders experienced in welding 4140 steel.

   As a result, the mount brackets were made out of a one-piece AISI 4140 steel billet. The billet was rough cut to a basic shape then machined to its final form in the annealed condition. Heat treatment and magnetic particle inspection followed machining.

More recently, the use of casting was adopted to reduce fabrication costs. The first article casting was made and passed X-ray and magnetic particle testing. A second batch of four was then poured at the foundry. During the machining phase, the machinists observed that the second batch machined harder than the first article. After machining, the brackets were sent out for heat treatment. The brackets came back from heat treatment with large cracks, typically near the heavy sections of the brackets.

An analysis performed by the KSC Analysis Laboratory revealed that the cracks were caused by a higher than allowable carbon and manganese content in the alloy. The foundry's computer printout indicated otherwise. A second analysis performed by the foundry, however, confirmed the KSC findings.

A subsequent investigation revealed that quality control personnel had not taken samples of the second pour. Later, they took samples from another pour which happened to have the proper alloy composition required for the brackets. Unfortunately, the alloy used for the unsampled pour, the alloy that was used for the brackets, was not the correct composition.

Again, the design process had been complicated by inadequate quality control during fabrication and manufacturing.

c. Skid Plate. The skid plate could not be mounted because of interference with mounting lugs. Moreover, the mounting holes did not line up. As a result, each skid plate was individually modified to fit its corresponding blast shield.

d. Shaft Interference. The main shafts interfered with the end cover plates in some blast shields. The shafts were not made to print; they were longer than what was called for in the drawings. Consequently, the shafts had to be remachined to proper dimensions and the end cover plates had to be shimmed. The ends of the shafts were also heavily lubricated prior to installation.

e. Main and Center Torsion Springs. The springs were cold formed and heat treated as specified. One of the main problems encountered in the manufacturing process was maintaining the required spring leg angles. The allowable tolerance for the leg angels is +/-1 degree. The spring manufacturer normally holds a +/-5 degree tolerance. However, due to the criticality of the engagement angle between the blast shield and springs, a +/-5 degree tolerance was not acceptable. To compensate, the test conductor determines how many shims are required so that the springs engage the blast shield at the proper angles during validation and acceptance testing.

CURRENT PROBLEMS

Since STS-26R, no failures have occurred: As of this writing, all the blast shields used have closed. Debris is negligible. However, several problems still must be addressed:

a. The blast shield survives only two launches. After the second launch, the hood's top surface is badly eroded. In several cases, burnthrough has been observed requiring that these blast shield assemblies be scrapped and replaced with new ones.

b. The provision that the springs must be replaced after each launch has proven costly.

c. The addition of 19-millimeter (0.75-inch) shims to the baseplate of the mount bracket moved the blast shield hood, slightly exposing the front edge of the SRB shoe to exhaust blast. This exposure results in SRB shoe erosion during some launches.

d. A lack of quality control is still evident in the fabrication process of the blast shields; specifically, fabricators are unable to hold the required dimensional tolerances.

CONCLUSION

Several improvements are still required to optimize blast shield operation. Some of them, being implemented as of this writing, are:

a. Scrapping the entire blast shield assembly after the second use is not economical. Some parts of the assembly, including the mounting brackets, the main shaft, the spring stops, the latches, and the shaft end cover plates are not directly exposed to the SRB exhaust plume and can still be used for at least four or five launches. Basically, only the hood and the springs require replacement. However, cannibalization of Ground Support Equipment designated as scrap is not allowed at KSC.

   The economics of cannibalization has been presented to Logistics engineers at KSC, resulting in the implementation of a new procedure allowing cannibalization for the refurbishment of blast shields that have been used for two launches. To date, the savings realized in the cost of refurbishing versus fabricating new blast shield assemblies has been approximately 35 to 40 percent.

b. The cost of machining the bracket from a steel billet is expensive. Economically, a casting is a less expensive approach. Less machining is involved and, consequently, a reduced possibility of failure due to human error in machining.

c. Further analysis and testing are required to determine if the springs can be used for more than one launch.

d. A redesign of the hood is being considered, including possible replacement of the welded hood with a casting and thickening of the top plates to allow more use out of each assembly. Another alternative is the use of a bolt-on-type sacrificial plate. The plate would allow easy replacement after burnthrough has occurred.

e. Quality control is being strongly emphasized. Space Shuttle flights involve human lives and expensive hardware and payloads. A blast shield failure could be catastrophic. Quality control, particularly during the fabrication process, must be emphasized. Engineers and designers can incorporate numerous factors of safety within their designs, but if they begin with defective products, the efforts of the design process can be negated.

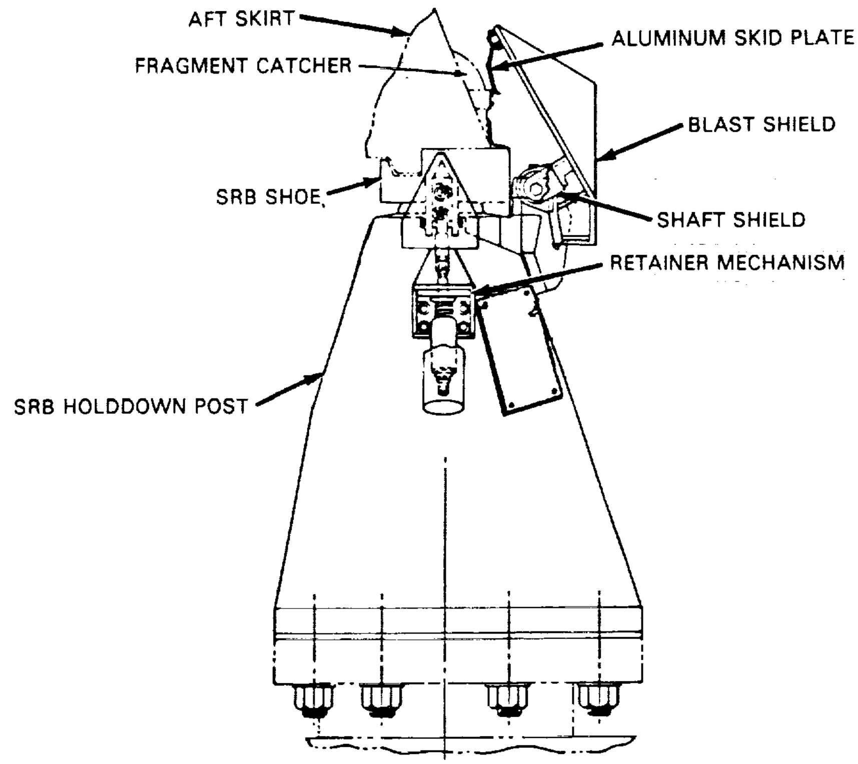

Figure 1. Holddown Post Blast Shield Installation (Original Design)

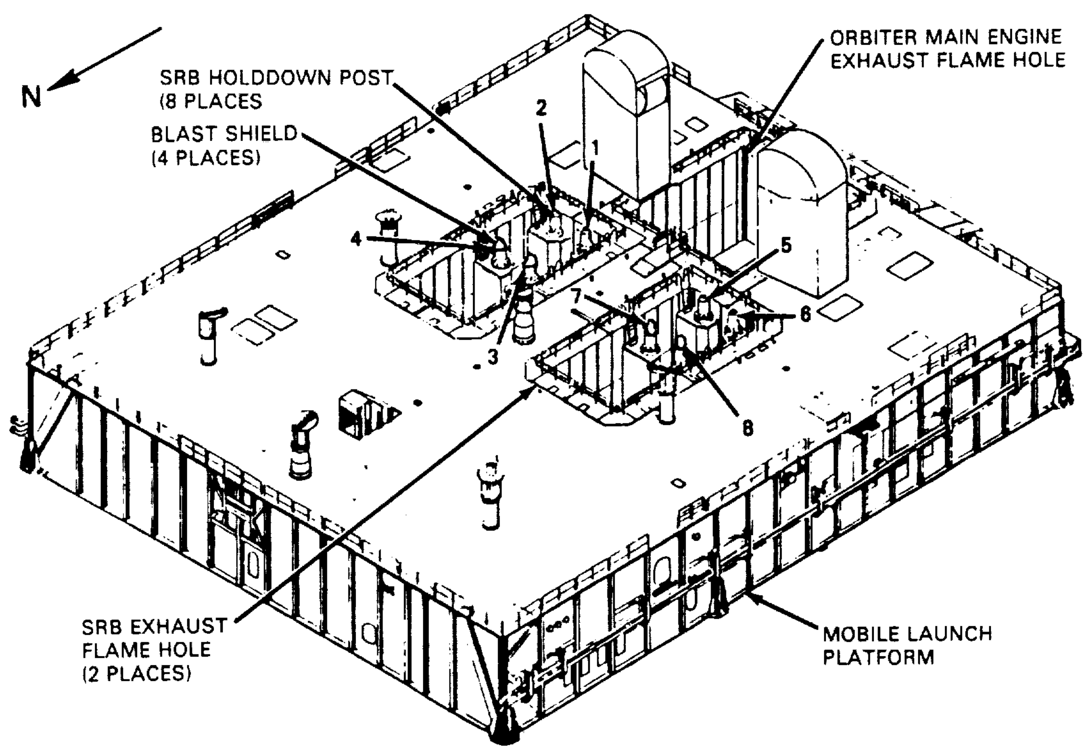

Figure 2. Blast Shield Locations on the Mobile Launch Platform

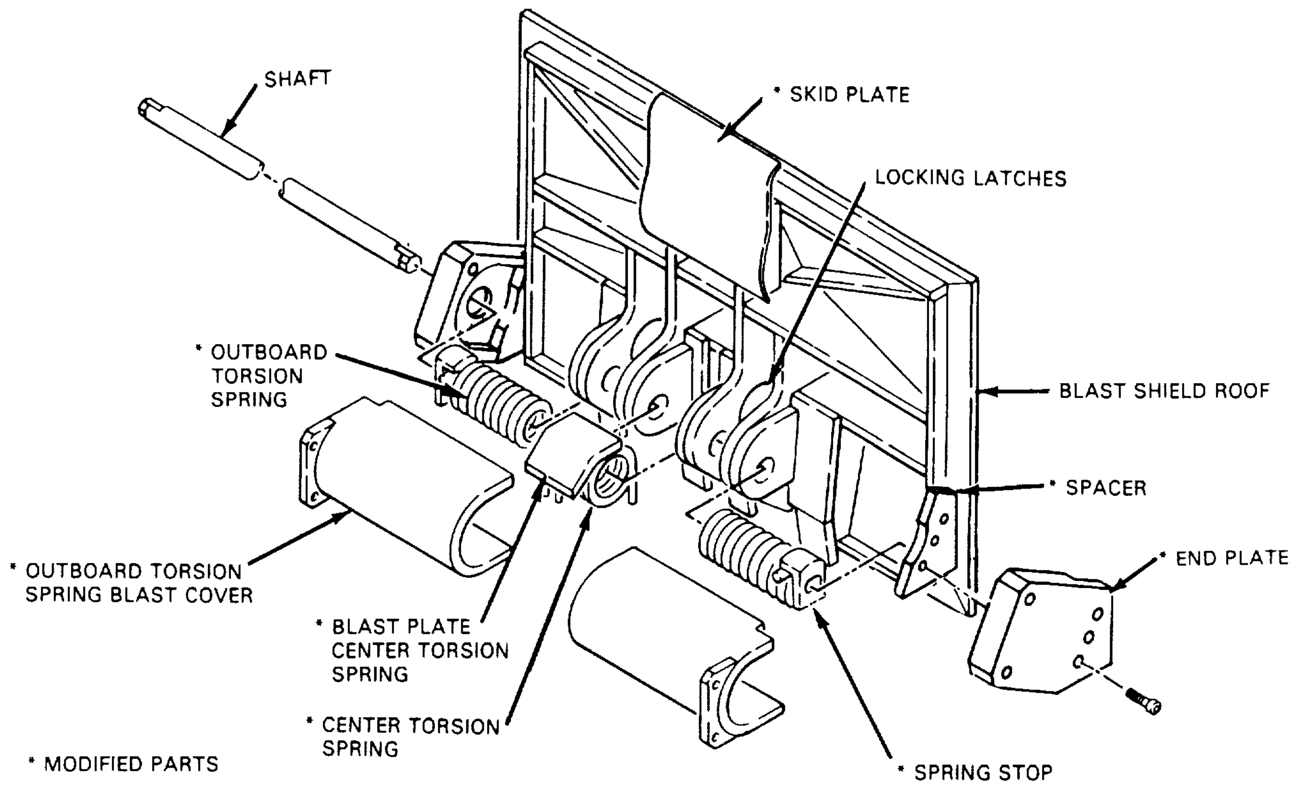

Figure 3. Blast Shield Modification and Installation

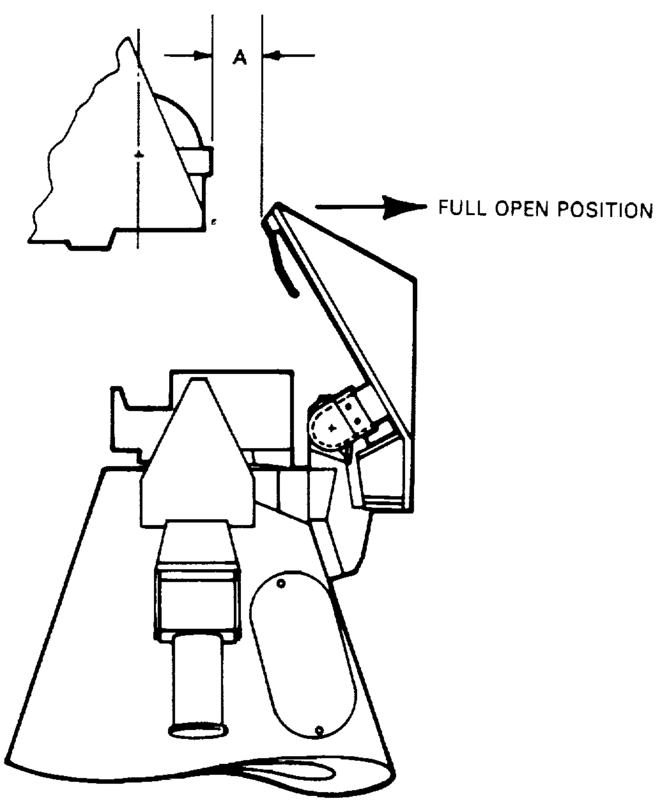

Figure 4. Blast Shield Full-Open Position

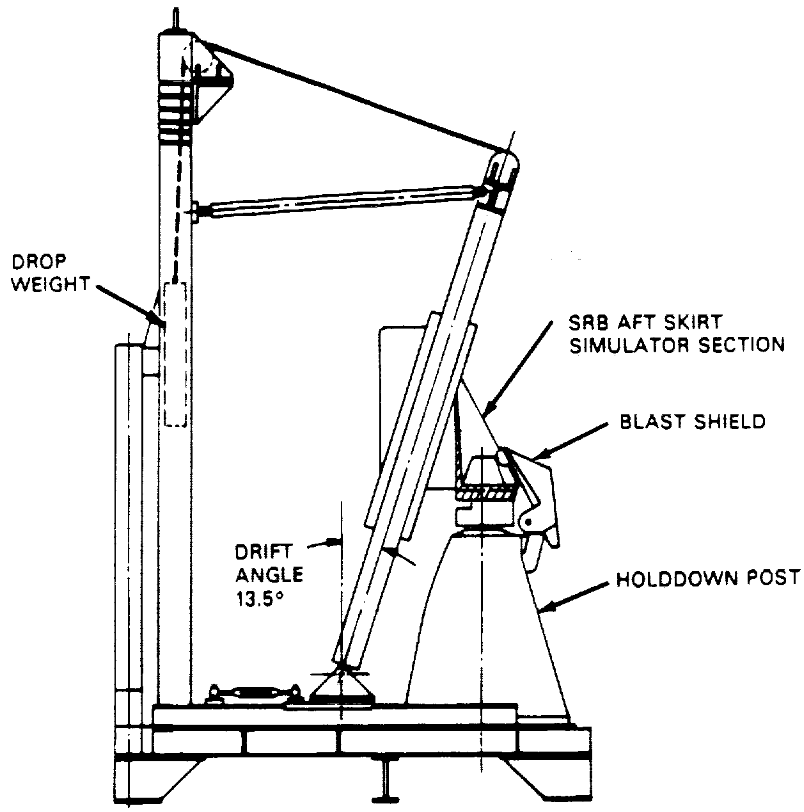

Figure 5. Lift-Off Simulator (LOS) Test Fixture

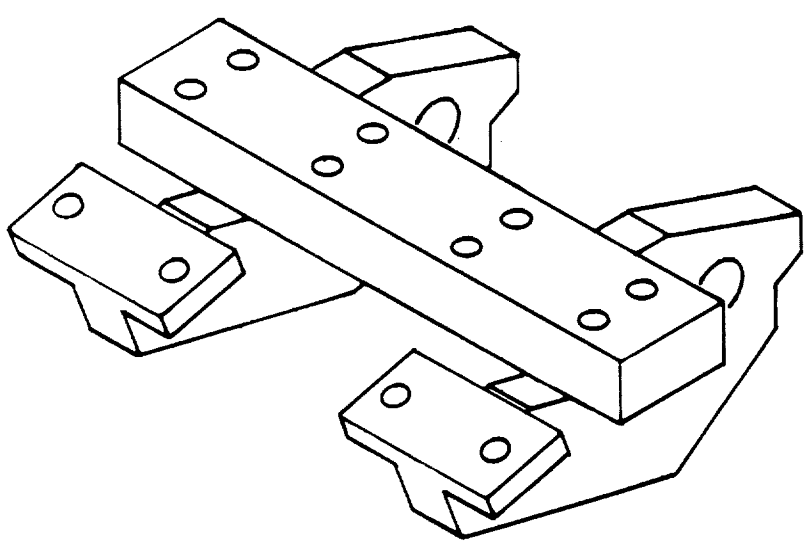

Figure 6. Mount Bracket (Current Design)