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THE CONCEPTION, BIRTH, AND GROWTH OF A MISSILE UMBILICAL SYSTEM

By Glenn W. Nordman

Martin Marietta Corporation

Orlando Division

ABSTRACT

This paper traces the design development of the SPRINT II and Improved SPRINT II Missile System (ISMS) umbilical system. It describes the unique system requirements, umbilical designs considered to meet the requirements, and the problems encountered and solutions derived during the design and development testing of the selected systems. The SPRINT II development effort consisted of design, analysis and testing activities. The ISMS effort involved the performance of an extensive trade study to determine the optimum design to meet the ISMS conditions.

INTRODUCTION

The task of the quick reaction, high velocity SPRINT missile is to intercept intercontinental ballistic missiles at relatively short range. The nature of the mission involves exposure to the nuclear environment, and increasingly severe operational requirements were imposed on the SPRINT missile systems as they evolved from the SAFEGUARD system to the SPRINT II system and the ISMS. These, in turn, required greater capabilities of the umbilical system. The task of the umbilical system is to transmit electrical signals and power between the missile and ground equipment prior to launch. The umbilical system must disengage and clear the launch envelope within system time constraints without adversely affecting the launch.

SPRINT II MISSILE LAUNCH STATION DESCRIPTION

The SPRINT II launch station with missile is shown in Figure 1. The station consists of a full-length steel launch tube with a circumferential compartment containing the umbilical system and related equipment. Two umbilical mechanisms are mounted within the Launch Preparation Equipment Compartment. The umbilical cables enter the launch cell through small holes in the cell wall and engage the missile near its tip. The missile contacts the launch

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cell wall sufficiently to permit pressurization beneath the missile during launch. Thus, the umbilical must retract fully behind the launch cell wall during launch. The umbilical facilities must not create discontinuities that could affect the missile during launch. As the SPRINT II missile umbilical receptacle location on the missile was determined prior to the umbilical design effort, the umbilical considered the missile interface only at that location.

UMBILICAL SYSTEM REQUIREMENTS

The umbilical mechanism must meet the following requirements:

Be easily, safely, and quickly connected and disconnected by personnel during maintenance operations, and must transmit electrical signals and sensor signals between the missile, launch station equipment, and interfacing subsystems.

Remain electrically and mechanically connected to the missile during benign, ground shock and airblast conditions.

Electrically disconnect upon command within 30 milliseconds (MS) during benign and ground shock conditions.

Mechanically clear the launch envelope within 70 MS without impeding missile launch or creating debris affecting missile launch.

Attenuate magnetic and plane wave fields over a wide frequency range. It must not adversely affect missile heat shield integrity.

SPRINT II UMBILICAL MECHANISM DESCRIPTION

The final design of one of the two identical systems within the launch station is shown in Figure 2. The mechanism consists of two electrical cable assemblies, each with a flexible metal shield that is attached to the connector, an umbilical frame with a fixed pulley, a compression spring and attached traveling pulley, and snubber box with decelerating material, spring pack and split nut explosive cartridge, and two wire rope cables.

The electrical cables are connected to the missile umbilical receptacles, and the cable shields are secured to the spring pack. One wire rope is attached to the spring pack and to the clevis held by the split nut explosive cartridge. One end of the second wire rope is attached to the umbilical frame and rove through the pulleys. The spring is compressed and the free end of the wire rope is secured to the clevis at the split nut. Upon command, the explosive cartridge fires, causing separation of the split nut segments. The clevis is released and the spring force is exerted on the wire ropes, which in turn pull on the electrical cable shields. Spring collets within the electrical connectors release when the disconnect load exceeds the connector spring load, thus disengaging the connectors from the missile receptacles. The force provided by the expanding spring pulls the connectors through the cell opening against the snubber material. A slight force is maintained on the cables, after retraction is completed, to assure their retention in the snubber box.

SPRINT II RETRACT MECHANISM DEVELOPMENT

During the SPRINT II retraction mechanism development program analyses were performed to determine the necessary umbilical capabilities required to meet system requirements. Engineering model equipment was fabricated and tests were conducted to verify the system's performance. The tests consisted of retraction in a benign, no ground shock, environment. Retraction tests with simulated ground shock conditions were also performed. Dynamic testing of the umbilical cable assemblies engaged with their missile receptacles evaluated connector retention capabilities.

The following major design problems were addressed during the design and development of the SPRINT II Umbilical system:

Missile-Cell Interface Compatibility

The conflicting requirements for a cell surface that would not affect missile launch and the desire for a large opening through which the umbilical cables and connectors could be retracted led to consideration of doors on the cell wall that would close after cable retraction. Structural, dynamic, and retract time considerations nullified that concept. A compromise solution involved the use of a 6.5 inch diameter hole through which the assemblies were retracted. The open hole introduced the possibility of excessive launch gas pressure loss. Computer analysis indicated that the design with the snubber box and decelerator material in position would reduce gas loss to acceptable levels.

Cable-Connector Motion During Retract

The umbilical system must accommodate, without disconnection, missile-cell relative motions approximately ± 2.0 inches in the vertical direction and ± 2.5 inches horizontally due to ground shock conditions. Successful retraction must be accomplished with relative motions approximately ± 0.1 inch vertically and ± 2.0 inches horizontally.

This requirement led to conduction of an extensive retraction test program to determine cable motions during retract. It was found that application of the retraction force to the connector at the missile was satisfactory as long as the umbilical cable remained straight in the cell. However, the changing distance between the cell hole and the receptacle due to missile-cell motions would likely cause cable bending which would result in an excessive amount of cable within the cell. Tests were conducted to determine the effect on retract action of slack cable within the cell. It was found that the cables were not stiff enough to retract through the hole, and the connectors struck the wall rather than passing through the hole. The point of load application was moved from the connectors to a point on the cables behind the cell face. Tests verified that, contrary to expectations, this change did not improve cable action during retract. The connectors continued to strike the cell wall when slack cable was introduced in the cell. The system was redesigned, with the addition of the snubber box spring pack to maintain a tension on the cables at all times. Dynamic tests to 70g from 0 to 400 Hz verified connector retention. Retraction tests under static and dynamic conditions verified the ability to retract without damage.

Time Constraints

The SPRINT missile system countdown is understandably short. The countdown timeline requires transmission of a signal indicating that the umbilical is disconnected prior to missile first motion. Missile motion during eject, however, commences prior to complete retraction. A maximum of 30 milliseconds is allotted between retract command and electrical disconnection; an additional 70 milliseconds, maximum, is permitted for complete retraction. This limit is imposed to avoid umbilical contact with the rising missile. Tests verified consistent disconnection times within 25 milliseconds and retraction times within 60 milliseconds.

Loads

The missile-cell ground motions introduce high loads that tend to separate the connector and missile receptacles. Continuous electrical continuity is vital and care must be taken to assure that even intermittent signal losses are avoided. Thus, the connector-receptacle retention load must be high enough to assure retention. This load must be overcome by the retract mechanism and, in addition, enough force must be applied to accelerate the assemblies to the cell wall within the allotted time interval. Upon reaching the wall, they must be decelerated without damage. During tests, the disconnection loads were 1000 to 1200 pounds per cable pair, retraction loads were 1200 to 1600 pounds per cable pair, and deceleration loads were 700 to 1100 pounds per cable pair. Of interest is the fact that proper design of the decelerator permits arresting loads lower than the maximum loads imposed during retraction.

Cost

The cost of the resultant umbilical system is an important design consideration, as the SPRINT program was engaged in a design-to-cost effort. The selected system must be technically correct and, in addition, must meet the design-to-cost target established for the item. The selected system has been determined to be cost effective.

SPRINT II CONNECTOR DESIGN EVALUATION

Three methods of connector retention were explored and tested for the SPRINT II umbilical application, Figure 3.

The first, a conventional ball detent connector, was discarded because the high concentrated loads applied to the shell by the few balls resulted in rapid wear. Also, the retraction force had to be applied at the connector to unlock the locking collar. The application of force at the connector end of the cable introduced the possibility of the cable bending within the cell, thus preventing retraction through the umbilical hole.

In the second design, two fracture bolts retained each connector to its receptacle. The bolts were captive on the connector and screwed into the receptacle. The bolts had a necked area that fractured as the retraction load was applied. This design was an improvement over the ball detent method, as the retraction force was applied to the cable outside the launch cell and point wear was avoided. The small diameter (0.064 inch) within the necked portion of the bolts was a major disadvantage, as inadvertent overtightening and fracture of a bolt could occur within the confined launch cell area. Inadvertent tool loss was also a possibility.

In the third design, which is the one selected for implementation, the connector is screwed into the receptacle for initial engagement. Thus, the engagement is initiated at no load. As the thread collar is tightened, a collet spring is compressed to achieve a 500-pound preload. When the disconnect load exceeds preload during retraction operations, a collar is retracted, permitting the peripheral collets to disengage within the shell and release the connector from the receptacle. A braided wire shield attached to the connector and extending through the cell hole provides mechanical strength and electromagnetic (EM) protection. The shield avoids application of force on the wire cable during retraction.

IMPROVED SPRINT II MISSILE SYSTEM (ISMS)

The SPRINT II missile had the same umbilical interface point as used in the earlier SAFEGUARD SPRINT missile. The SPRINT II design evolved about that interface. However, for the ISMS the missile guidance control system was revised, also potential motor changes were evaluated. The guidance package configuration and increased system capabilities made a change to the umbilical interface desirable. The motor changes provided the opportunity to consider using a tailplug umbilical design on ISMS. Thus the interface could occur in a variety of radial and longitudinal locations. In addition to the above, the ISMS EM and ground shock levels exceeded the SPRINT II requirement. To assure adequate consideration of all aspects of the umbilical function to meet the ISMS requirement, a trade study was performed covering the mechanical and electrical portions of the system. All design and design support disciplines were represented. Five umbilical disconnection and retraction concepts were investigated as shown in Figure 4. Several alternative techniques were proposed under each concept. The electrical portion of the system was also evaluated. Eight types of connectors were reviewed. The compatible connector-mechanical systems were selected.

Mechanical Design

Retract Concept - Each technique explored within this concept requires that the umbilical cable be retracted through an opening in the launch cell wall in a manner similar to that of the SPRINT II system.

Several methods of providing the motive force were investigated: mechanical spring, stored gas pressure, missile exhaust gas pressure, and missile motion.

Flyaway Concept - In each of the techniques studied under this concept, the umbilical cable remains engaged with the missile as it begins its eject motion. When the umbilical is disconnected, it continues its upward motion until the end of the tether line is reached. The cable then moves outward from the missile to clear the launch envelope. As the cell end of the umbilical cable is secured at the upper end of the launch station, the cables do not have to be retracted to clear the envelope. This concept eliminates the requirement for retract mechanisms, spring pack mechanisms, and snubber devices. Increased cable shielding is required due to the higher EM levels above the launch station.

Tailplug Concept - This concept theoretically offers the advantage of a passive umbilical mechanism, as the umbilical remains fixed in position and the missile moves from it during eject. The problems associated with this concept include assurance of positive and accurate engagement of the blind mated connectors during missile installation and the missile design impact of routing the additional electrical wires from the aft end of the missile to the guidance section.

Shear Concept - This concept eliminates the retraction mechanism by using other missile support items in a dual-purpose role. The umbilical cables and connectors are secured to one of the missile forward support wedges. As the wedges move with the missile during eject and fly free as they clear the launch cell, they also disengage the umbilical connector and carry it clear of the launch envelope. Several of the techniques investigated under this concept severed the umbilical cable during eject to obtain cell-missile separation.

Test-Only Concept - This concept questions the necessity of a continuous umbilical link between the missile and the launch station. Periodic testing of the missile to verify missile condition was investigated. Extensive missile changes were required to accommodate this concept.

Electrical Design

Concurrently with the mechanical system trade study, an electrical system trade study was also conducted. Six connector configurations, with several variations of each, were evaluated.

The first configuration uses the connector developed and tested for the SPRINT II system.

The second design was developed for the ISMS program where the increased EM level prohibits the exposure of the electrical contacts to the EM environment for even the brief period during and after separation in the launch cycle. The flush mounted umbilical design solved this problem.

This connector system (Reference 1) consists of a spring-loaded, shielded plug on the umbilical cable and a receptacle on the missile. The receptacle is a rear flange-mounted sealed unit with socket contacts. The face of the receptacle is mounted approximately tangent to the exterior conical surface of the missile flame shield.

Figure 5 shows the unmated plug and receptacle. A heat shield is incorporated on the face of the receptacle rotating shutter with minimum cleavance through-holes for the mating plug electrical pins. The rotating shutter base has holes that are larger than the heat shield holes.

To engage the plug and receptacle two asymmetrical guide/alignment pins on the plug half are inserted into the shutter, and the plug and shutter are rotated counterclockwise 10 degrees.

The guide/alignment pins then engage the guide holes in the receptacle base and the plug electrical pins initially engage the electrical sockets in the receptacle. The ball detent quick-release pin is engaged into its socket in the center of the assembly. The coupler nut, which is restricted in the axial direction on the quick-release pin, is turned to fully engage the electrical pins through the shutter holes into the receptacle sockets, depress the deadface pin protector plate in the plug, and compress the eject-separation spring in the receptacle. The spring-loaded deadface plate protects the electrical pins during handling and initial mating steps. To separate the plug and receptacle an axial pull is applied to a wire rope lanyard attached to the ball detent quick-release pin. The pin is released. The eject-separation spring force and axial load disengage the units. After disengagement, the spring-loaded rotating shutter closes over the socket contacts in the receptacle.

A third configuration considers a commercially available connector design in which the connector is disengaged by spring force. The spring is released electrically.

Two additional connector concepts considered are special designs that are compatible with the tailplug concept and test-only concept previously noted. The sixth configuration is a special design for use with a receptacle mounted on a door within the missile. When the connector plug is disengaged, the door closes for flight.

The flush-mounted connector was selected for further evaluation.

CONCLUSIONS

The development of the SPRINT II and ISMS umbilical system design emphasizes again the necessity for a thorough understanding of requirements, consideration of a wide range of optional designs prior to establishment of the preferred design, analysis to determine equipment capabilities required to fulfill the requirements, and the desirability of test activities to substantiate the analytical effort and disclose anomalies.

REFERENCES

1. KERR, J. MORGAN, Flush Mounted Umbilical Connector, EMP & RFI Attenuating. Ninth Annual Connector Symposium

Figure 1. SPRINT II Launch Station

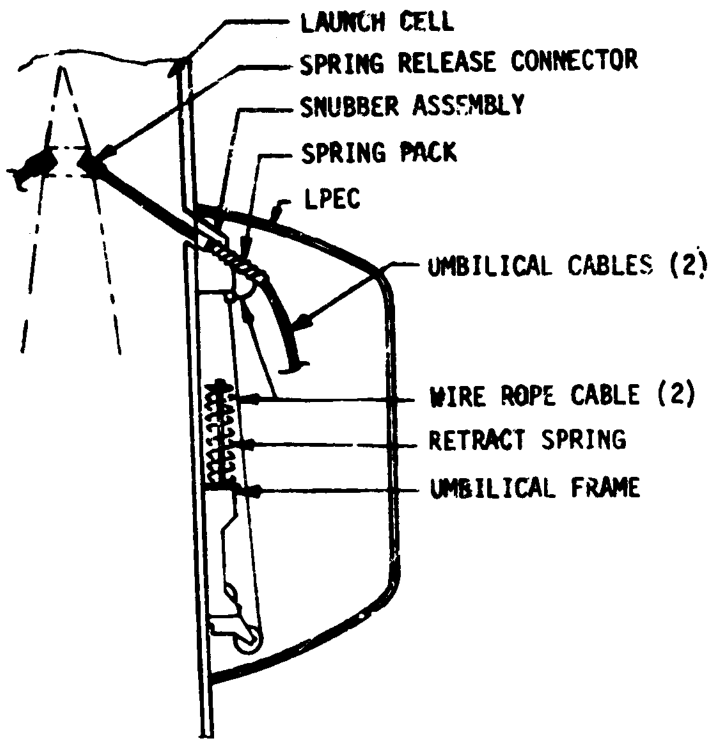

Figure 2. SPRINT II Umbilical Retract Mechanism

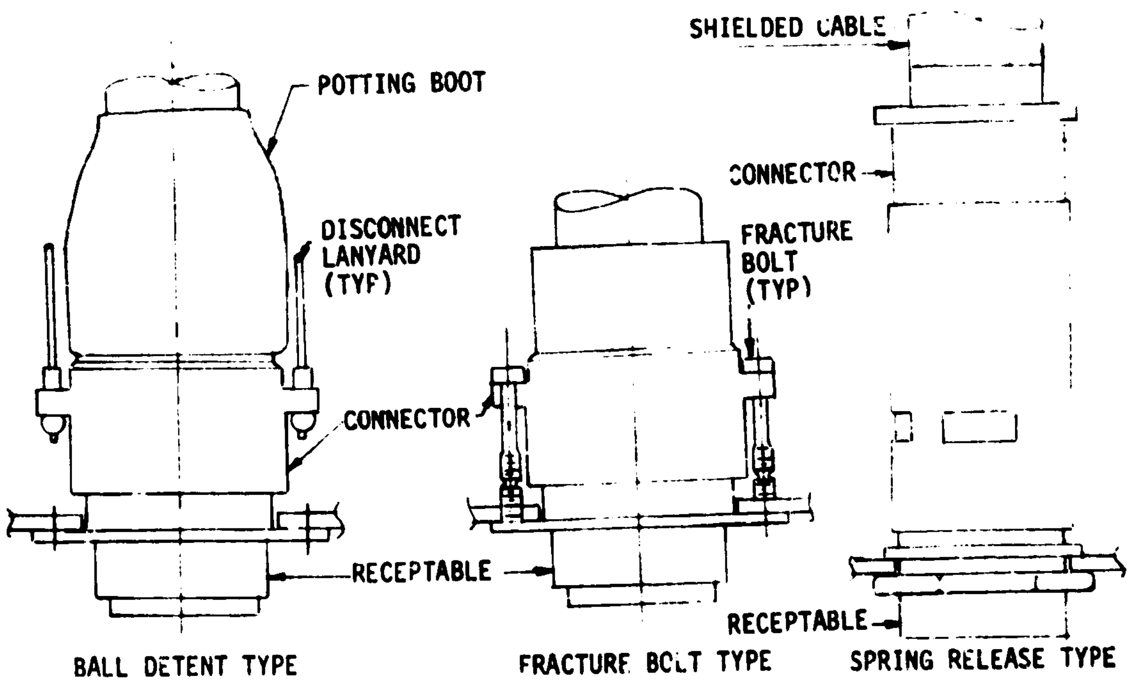

Figure 3. SPRINT II Connector Configurations

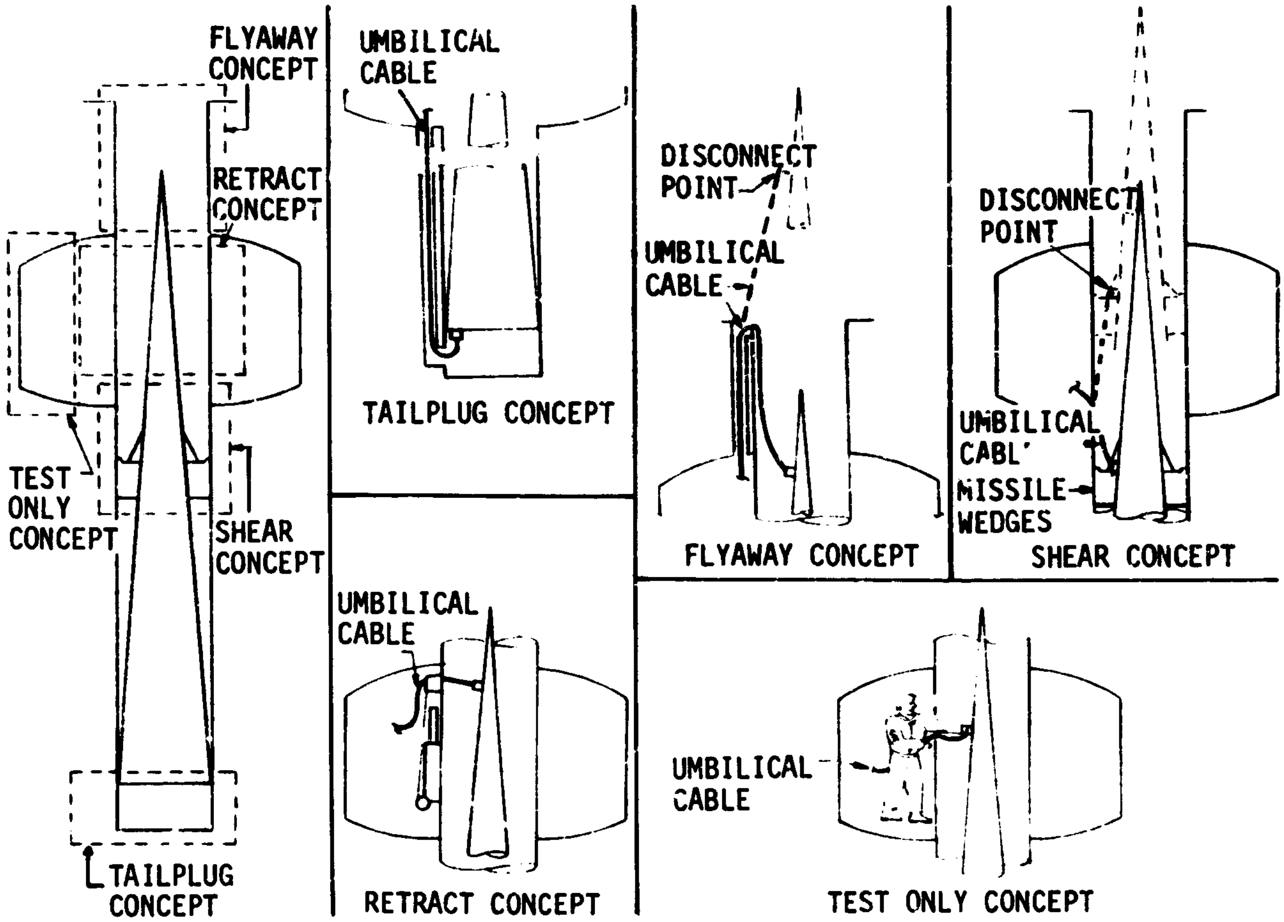

Figure 4. ISMS Umbilical Concepts

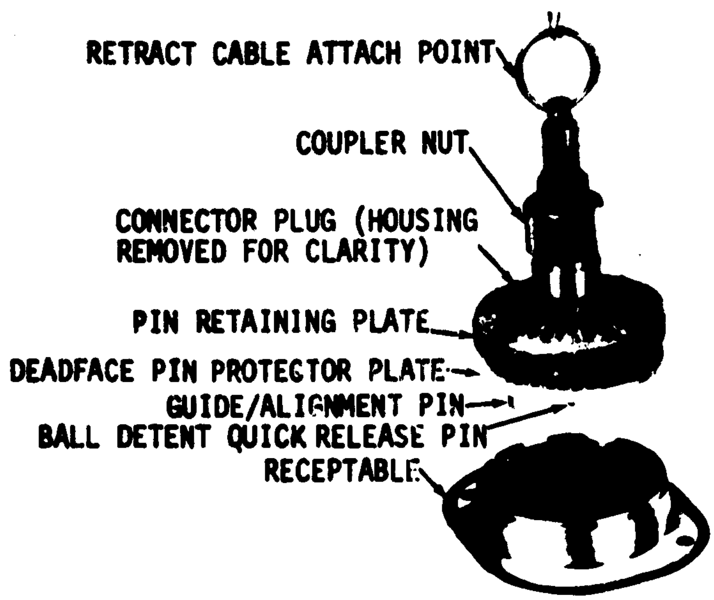

Figure 5. Flush Umbilical Connector Assembly

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