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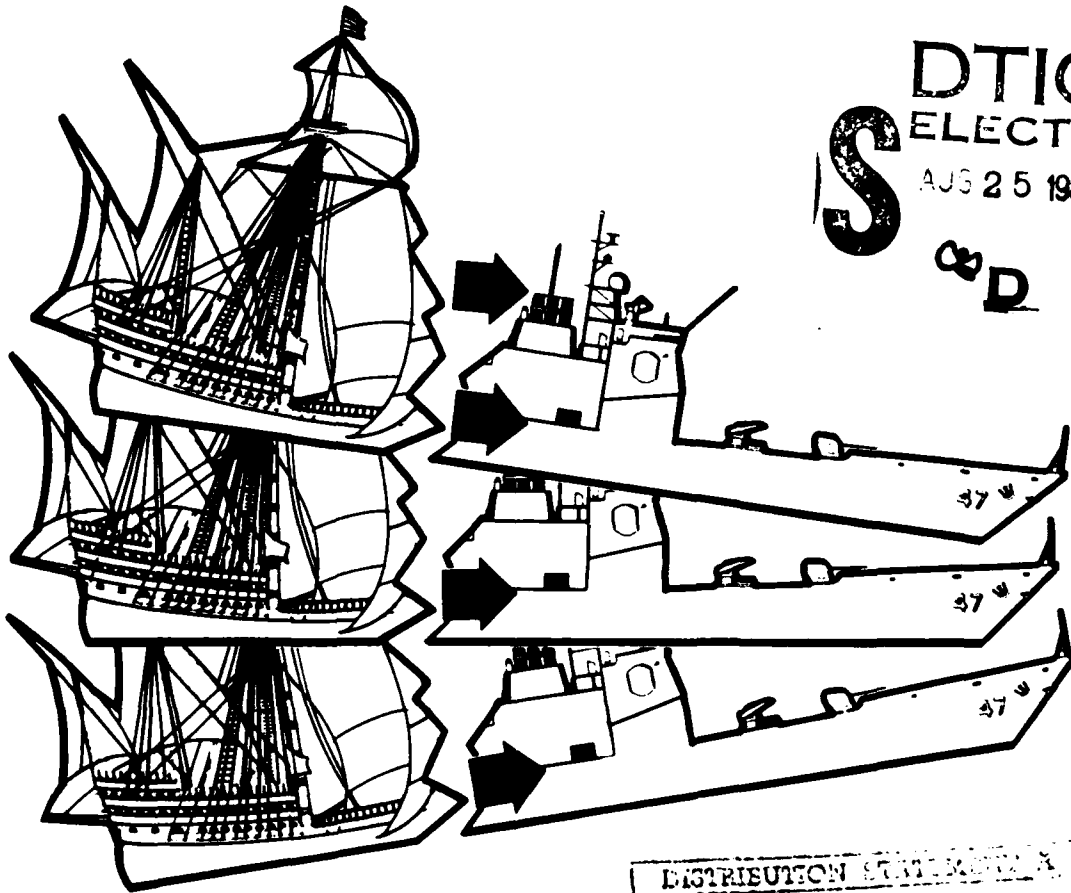


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VLS: A CHALLENGE MET, AN OLD RULE KEPT
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ABSTRACT

The U.S. Navy's first surface combatant with the MK-41 Vertical Launching System (VLS) was commissioned in the fall of 1986. The introduction into the Fleet of this advanced launching system, with its ~~key attributes~~ (i.e., high firepower, high survivability, etc.) requires understanding of new aspects of missile launcher safety.

This article ^{discusses} ~~will discuss~~ the MK-41 VLS, its safeguards, its unique safety related differences from other launching systems and the "new culture" required of ~~our~~ Navy system operators. Note that for the MK-41 VLS, there is no "missile on the rail" to be observed; all missiles are always on the rail, ready for firing; and missiles themselves are never seen or moved as a reminder of ordnance hazards, but the "wooden round" is always present.

MK-41 VLS safety has been and is the centerpiece of its design and additionally it must be operated, observing the Cardinal Rules of MK-41 VLS safety:

- Maintenance and operation only by trained personnel using authorized procedures;
- Dead electrical missile interface until intent to launch; and
- No mix of ordnance and missile simulators.

Keywords: Guided missile safety; Guided missile launchers; Weapons control systems. Guided missile personnel.

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Notations, Definitions, Abbreviations

Anti-Air Warfare	AAW
Anti-Submarine Warfare	ASW
Anti-Surface Warfare	ASUW
Built-In Test Equipment	BITE
Canister Safe and Enable Switch	CSES
Combat Information Center	CIC
Critical Function Interrupt Switch	CFIS
Daily System Operability Testing	DSOT
Launch Control Computer Programs	LCCP
Launch Control System	LCS
Launch Control Unit	LCU
Launch Sequencer	LSEQ
Motor Control Panel	MCP
Occupational Safety and Health Act	OSHA
Vertical Launching System	VLS
Weapons Control System	WCS

VLS: A CHALLENGE MET, AN OLD RULE KEPT

INTRODUCTION

"Batteries Released!"

With those two words, USS SAN JACINTO (CG-56) commenced simultaneous missile launches at four in-bound supersonic air targets, a hostile submarine contact identified as an OSCAR class laying some 15,000 yards astern, a KIROV class cruiser 200 miles SE of the carrier battlegroup in the middle of preparations for launching her own cruise missiles and finally, at a tactical airfield servicing the BACKFIRES presently under attack by a flight of F-14s. Sounds a bit far fetched to say simultaneous, you're thinking? No single ship can actually be firing on all those targets at the same time, you say?

Up until September 20, 1986 you would have been correct. But on that day, with the commissioning of USS BUNKER HILL (CG-52), the Surface Navy gained that capability and a lot more with the introduction of its new main battery, the Vertical Launching System (VLS). Designed with the capability to fire Anti-Air Warfare (AAW), Anti-Submarine Warfare (ASW), and Strike and Anti-Surface Warfare (ASUW) missiles at the same time, VLS indeed makes the opening battle scene a reality.

This paper will describe this new launching system and some of its, in the words of VADM J. Metcalf (OP-03), "revolutionary applications for Surface Warfare." It will uncover and examine some of the significant aspects of this new system which don't often receive much attention...that is, until something goes wrong. Then, as in the case of any accident or serious system malfunction, it receives everyones closest scrutiny. I am speaking of the safety of this new launcher and the principles that went into its design and development to allow it to safely store and then shoot multiple missile types all at the same time. I am also speaking of some of the new operational aspects of VLS that must be carried into the Surface Fleet to safely operate this revolutionary new system. For if it isn't designed safe and operated safely, no matter how much capability increase VLS brings, it is all for nought.

OPERATIONAL REQUIREMENTS

As in the design of all new systems, whether they are automobiles, airliners or warfighting equipment, new capabilities bring design trade-offs. Design trade-offs for capability in turn, lead to operational, administrative, logistical and a whole host of other trade-offs including those affecting safety. Unlike other trade-offs, safety can never be compromised. Safety in the design of US Navy systems has always been of paramount concern. If allowed to become the end in itself, it can severely limit or even make impossible the achievement of real performance gains. Remember the Occupational Safety and Health Act (OSHA) cartoons that first circulated with the passage of this law. Certainly they graphically described the problems facing any program attempting to introduce a new system if safety were allowed to become the sole overriding requirement. The challenge of VLS, therefore, was to maintain a balance of requirements, make real and significant gains in warfighting ability, yet not compromise safety in its entire Service-Use

profile. The only way to accomplish this was to system engineer safety into the design from day one.

In the case of the Vertical Launching System, threat scenarios to surface ships from air-attack created the need for a rapid firing surface-to-air missile launcher with an extremely short reaction time (the time from missile selection to missile away) with the ability to carry and fire more missiles than existing launchers. In addition, this new launcher was to have the capability to launch at least two other missile types and provide nuclear weapons capability. This call for a high firepower launcher is also carried with it the need to reduce the manning associated with operation and maintenance. If you translate these very general requirements into other words, one can begin to appreciate how critical it was to consider all aspects of launcher safety from the onset. Some of the more significant considerations follow.

The challenge to store and fire multiple missile types in a single launcher is not new. The challenge to do this with ready-for-launch ordnance stored in density aboard ship roughly equivalent to that of a bulk storage magazine seen in our weapons stations and still provide a high performance firing capability IS NEW.

High density leads to the vertical stowage of all missiles. Rapid response and firing rate required consolidating the normal missile launch "rail" into the missile storage condition, giving the ability to launch all missiles from their stored vertical position and eliminating the need for handling operations associated with taking a missile from its "ring" and running it out on the "rail," present in most other shipboard launchers. It also removed the need to train and elevate a missile prior to firing. This single fundamental change allowed the significant improvements VLS brings in the number of missiles a ship can now carry as well as its much shorter response time and substantially higher firing rate. This simple change also carried with it, several revolutionary considerations with regard to operation and safety. Early design effort had to recognize and engineer into VLS, the solutions to answer such issues as:

- *Each missile is now "connected" to its firing circuits as soon as it is loaded in the launcher.

- *Each missile is ignited within the hull of the ship and literally flies itself out of the ship on its way to the target.

- *Each missile is never seen by the crew before they fire it since it arrives already loaded in a canister which becomes part of its firing cell.

- *Aside from the difference in missile and canister lengths, there is no at-a-glance way to discriminate missile types or visually check the condition of a missile prior to firing.

- *Since missiles arrive as "all-up wooden rounds," they cannot be disassembled or tested aboard ship.

Rapid response, high firing rate and reduced manning also led to increased automation. VLS was designed as an UNMANNED SYSTEM. At first glance, it is

perhaps a major step forward. But automation, while generally providing faster operation with fewer people, also carries the insidious penalty of taking the man out of the loop. After all, this launcher was intended to provide new capabilities for concurrent launching of multiple missiles at multiple targets. But how much have we come to depend on that "man in the loop" for ensuring that things are working correctly and to be there to handle all unanticipated situations that only time and circumstance can provide? With the increased automation that the threat demands, we are forced to remove that man one step farther back from being in a position to step in and exercise control. Again, not entirely a new proposition, but one which when dealing with an ordnance requires early recognition and intensive design effort to deliver a safe product to the fleet operators. One which, once delivered, also requires corresponding recognition, understanding and adjustment on the part of the operator.

Automation has its drawbacks -- for example those little innocent Os and Is which continue to produce incredible events when just one is not in its proper place. Increasing complexity in modern computerized systems has resulted in everyday reports of massive financial transactions being misrouted, misplaced or misrecorded as a result of a computer program "bug." Bugs are reported to have killed or severely injured patients undergoing treatment by computer controlled medical equipment. Bugs have also created many incidents within the military that we all remember. It takes little imagination to think of what the results of mixing computers and ordnance can be if the most stringent precautions aren't taken to safeguard their interaction. A well known rule based on painful experience is that ORDNANCE IS UNFORGIVING! The challenge in VLS to FULLY AUTOMATE a high performance shipboard multi-warfare missile launcher was indeed formidable.

WHAT IS A VLS

With an eye toward the system and functional safety features, which will be discussed later on, this section will guide you through the major VLS components follows.

As an overview, the Vertical Launching System is a very simple telephone switching network providing the communications paths for missiles and their weapons control systems (WCSs) to talk to one another (Figure (1)). As a switching network, it provides the necessary safeguards to ensure that only the correct combination of parties (i.e., WCSs and missiles) communicate. The Vertical Launching System is a controller and scheduler. It enforces a set of rules each system must follow in order to safely and properly conduct a missile launch. It manages and distributes the command stream coming from a WCS or several WCSs, monitoring all communications for proper order. It distributes the communications load over the system, allowing up to 32 simultaneous conversations. As a scheduler, it performs any launcher related functions required to fire a missile (such as opening a hatch) at the proper point in the launch sequence.

VLS is modular electronic launcher assembled from basic building units. A closed canister containing a missile, when mated with a module, forms a distinct launch cell. Each module contains eight cells (rails) and can be combined with other modules in launcher configurations of up to sixteen modules per ship. Each module grouping is combined into one or more launcher

assemblies and landed in a ship to become an integral part of the hull assembly (Figure (2)). Presently, AEGIS cruisers carry sixteen modules in two groups of eight, one forward and one aft; the SPRUANCE Class destroyers have one eight module launcher located forward; and the ARLEIGH BURKE Class destroyers are planned to have twelve modules in their launcher, four forward and eight aft.

VLS is also a very large shipboard storage magazine for a collection of smaller storage magazines--the canisters--containing any of three missile types--STANDARD MISSILE, TOMAHAWK and ASROC. The launcher is designed to carry any missile type in any cell. As a magazine within a launcher, its individual canisters provide all firefighting as well as all security and environmental protection required of a magazine for the safe storage of ordnance.

The Vertical Launching System, as is quickly seen from this simple overview is a hybrid of many different species combined in such a way that the whole is much much greater than the sum of the parts. Now let's look at the launcher component parts in more detail.

As indicated earlier, an eight-cell module, called the standard module, is the basic building block replicated to form a launcher assembly. Each module contains all the equipment necessary to function as its own independent launcher with the exception of external power distribution electronics, lighting and communications assemblies which are contained on only one module--designated the the systems module--of any module grouping. Each module consists of a lattice work structure connecting a deck and hatch assembly with a plenum base and uptake assembly. The plenum and uptake provide the missile exhaust gas a path to the atmosphere which allows ignition of each missile within the ship's hull (Figure (3)). This gas management system, because it redirects the missile blast and exhaust below deck to the outside, is lined with a heat resistant ablative material to withstand over multiple missile firings, the significant pressures and high temperatures generated in a rocket plume. The plenum and uptake are capable of containing and surviving a full burn restrained firing without loss of gas management integrity.

A third module type, called the strikedown module is identical to a standard module except that three firing cells are replaced by an articulating crane assembly mounted on an elevator. This module provides canister and equipment handling capability for rearming and maintenance operations.

The only moving mechanical components of the launcher during firing are the individual cell hatches which cover and protect each cell and the uptake hatches. They are designed to provide topside ballistic protection with watertight integrity yet open quickly by means of individual drive motors. Each module contains an integral water deluge system which connects to each canister to provide a water cool down in the event of high canister temperatures or a missile restrained firing. This deluge system is inhibited in a canister during its own missile's firing.

Two electronic assemblies called the launch sequencer (LSEO) and the motor control panel (MCP) are mounted on each module lattice structure. The MCP provides power distribution to each of the module's eight cells and controls

the activation of the module hatches on commands from the LSEQ. The MCP also activates the module plenum drain system in the event water enters the module plenum.

The LSEQ combines and integrates digital electronics with electro-mechanical relays to provide the second level command and control communication functions for all module and missile interactions. As such, it forms one part of the launch control system (LCS). The LSEQ also provides the electronics to control and conduct module level self-testing using built-in test equipment (BITE). Unless the launcher is actually firing missiles, BITE is periodically run to provide a constant health check and module status report. A continuously powered section of the LSEQ monitors several hazard circuits on the module and within each canister and provides the status of these conditions to several locations outside the launcher spaces. Internally, each LSEQ is split into two sections with each section controlling four of the eight module cells. This feature enhances the modularity of the design and restricts the effects of casualties to a half-module.

Redundant power supplies are mounted beneath each module's power access walkway, providing module and missile power. They are controlled by the LSEQ and provide external operating power to missiles until just prior to launch. They are also the energy source which initiates commanded major ordnance functions such as booster ignition and missile restraint release.

A damage control junction box and local status panel are assembled with each group of modules to provide a complete interface to the ship's damage control center and combat information center (CIC). Up-to-date hazards (e.g., high temperature conditions) and system status information on each missile and module is indicated on the status panel and passed to the ship's damage control center or CIC. The local status panel also controls launcher power, enables the strikedown and anti-icing systems and provides a manually operated hard-wired interrupt to prevent missile launches while the launcher is occupied.

The VLS canister is a corrugated metal container with internal adaptive hardware for missile restraint, shock mitigation and safe and arming systems peculiar to each missile type. The canister functions as the packaging, handling, shipping and transportation container for its missile as well as its launch rail and gas management cell. It contains an integral deluge piping and manifold spray assembly which delivers 40 gallons of water per minute when activated by a high temperature condition within the canister or during a restrained firing. The canister is loaded at a weapons station and sealed with a forward fly-through cover and aft blow out closure to provide complete environmental protection. An electrical cable assembly within the canister mates the missile with its LSEQ umbilical. Each canister contains either a canister safe and enable switch (CSES) or a critical function interrupt switch (CFIS) which mechanically interrupts all ordnance lines to the missile. It is accessible from the module walkways and must be manually activated prior to missile launch. The LSEQ monitors each switch position and reports its "safe" or "enabled" position status. Each canister contains a coded plug which identifies the missile it contains. This plug is configured by the weapons station at the time the missile is encanistered and is inserted in a canister cable harness connector prior to closure.

VLS uses three canister configurations today (Figure 4): the MK-13 for Standard Missile, the MK-14 for TOMAHAWK, and the MK-15 for Vertical Launched ASROC. Since the launcher is sized for the largest missile type, the 264" TOMAHAWK, 36" adapters are used with the MK-13 and MK-15 canisters to mate them to the module plenum.

The last major component of the VLS is the computer programs and equipment which are the heart of the system. The launch control unit (LCU) and launch control computer programs (LCCP) complete the launch control system. This digital system provides the redundant interfaces back into the combat system and out to each launcher to connect each weapons control system to its missiles through the appropriate launch sequencers. This subsystem serves as the first level of command, control and communication for VLS and is located outside the launcher spaces in the ship's computer spaces. The LCU and its associated teletype, video and mag-tape input/output peripherals are completely redundant with each half able to control all missiles in up to sixteen modules. Normal operation calls for each LCU to share the total inventory with a single LCU assigned primary responsibility for managing half the missiles on a per launcher basis.

Having discussed the significant components that make up a VLS, it is time to briefly describe their collective operation before describing how they safely perform their demanding mission.

SYSTEM OPERATION

When the Vertical Launching System is powered up, prior to entering one of its three operational modes, it performs a self-initialization. To do this, it conducts a system level BITE by commanding individual module built-in tests, collecting the results and then reporting its operational readiness status to its own teletype and magnetic tape drive and any weapons control system that is on-line. Concurrent with the BITE, it is also establishing its present inventory by querying each launch sequencer which in the course of their own power up sequence has established a module level inventory of each of its own eight cells. This inventory is established by the LSEQ reading hardwired canister coding plugs assembled with every missile and containing a unique sixteen bit ID for each missile type. The system inventory is subsequently reported at the LCU peripherals and passed immediately to on-line WCSs.

Upon completion of this initialization, the launcher assumes a STANDBY mode awaiting commands from any WCS. Standby is the normal mode the launcher will operate in more than 90% of the time. While in this mode, periodic BITE tests will be automatically commanded to maintain a fresh launcher availability status. Also in this mode, the LCUs will continuously check each digital interface with each on-line WCS as well as to each of its own LSEQs. When commanded, the launcher will transition in milliseconds to one of two other modes.

In the SIMULATION mode, VLS, while maintaining inactive launch circuits to the LSEQs, provides normal but simulated launch responses to a WCS to allow weapon systems testing or combat systems testing or combat systems training. The crew can call for simulated inventories or system faults while the actual inventory is maintained safe. Actual launcher status conditions are gathered

and kept ready for immediate reporting when the launcher is returned to standby.

The third mode of VLS, called READY ALERT, is that commanded to select missiles for actual launch. All launch related orders are executed and all other mode commands ignored until ready alert is removed by the original WCS(s) which commanded it. Each WCS must order VLS to ready alert (even if VLS is already conducting launches with another WCS) in order to shoot its own particular missiles. While in ready alert mode, the launch enable function must be enabled either in the CIC or at the local status panel in order for launch operations to proceed. Likewise, all canister switches intended for launch must be in the enable position. The status of each switch position is part of the data reported on a continuing basis, first during initial inventory and then through constant monitoring. Missiles may be selected by the VLS. Selection by VLS is based on system criteria for such things as uniform inventory depletion across modules, weight and moment, module ablative wear and missile deconfliction.

Each module is designed for simultaneous preparation of two missiles, one on each half module (4-Cell), allowing an AEGIS cruiser for example, simultaneous preparation of 32 AAW, ASW, or Strike and ASUW missiles in any combination. At the final stages of missile preparation, VLS begins opening hatches and performing other launcher functions necessary for launch. When these operations are completed and verified by both digital and mechanical checks, booster ignition commands are passed to ready missiles and they fly themselves out of the launcher. Cell hatches are closed when sensors indicate that the missile is clear of the launcher. If any malfunction occurs during this entire process, automatic safing routines are executed and replacement missiles are selected. Since AAW targets have the highest priority, VLS allows interruption of a TOMAHAWK initialization for selection and firing of an SM-2 from the same half module. VLS will then resume the TOMAHAWK initialization without loss of data. This identical capability is true in the event the second highest priority warfare area requires it. At the end of an engagement, the WCS(s) order VLS back to standby mode and receive an updated inventory and availability status. A typical AAW launch sequence is shown in Figure 5.

SYSTEM SAFETY CONCEPTS AND TENANTS

VLS was designed as an unmanned missile launcher under the operational control of the weapons systems of the missiles it launches as part of either an integrated or federated combat system architecture. To meet its requirements and faithfully yet safely serve many potential masters, a great deal of system safety engineering had to be accomplished within the launcher as a function of its design as well as the designs of those systems it serves.

At the very beginning of its demonstration and validation phase, VLS established clear safety concepts and design tenants to be followed rigorously during the course of its development and deployment. These concerns and tenants became the rules that guided detailed design and the course of the many decision trade-offs which in turn directly determined its operation and maintenance procedures.

COMPLETE AND ABSOLUTE ISOLATION OF ALL ELECTRICAL SIGNALS FROM A MISSILE UNTIL IT IS INTENDED TO BE LAUNCHED ATTACKS PREMATURE OR INADVERTANT INITIATION OF ANY ORDNANCE AT ITS MOST FUNDAMENTAL LEVEL AND ESTABLISHES A SAFETY PRECEPT CONSISTENT WITH THE STOWAGE OF A MISSILE READY FOR FIRING ON ITS LAUNCH RAIL! If you haven't guessed already, first and foremost in these simple yet formidable covenants is the rule that power is never applied to the encanistered missile until the missile is intended to be launched.

Using the first tenant as a cornerstone, the requirement for multiple INDEPENDENT INTERLOCKS to safeguard EVERY ordnance function was added. These interlocks had to be designed to form a hierarchy of safety layers throughout the system, capable of progressive removal as conditions of readiness increased.

In tandem with this second tenant, a MINIMUM LEVEL OF THREE interlocks was set as a threshold and each set of interlocks had to include both independent manual and automatic operations. This design principle allowed for putting the man back "in the loop" at critical points in the launcher's transition to increased ship's readiness conditions, yet still allowed for full automatic operation in the ready alert mode, i.e., "go to war."

Lastly, in concert with the modular and redundant design initiatives keyed to performance, the system design for safety had to RESTRICT ANY FAULT IMPACTS to the module or individual cell level to minimize their effects on the total system.

These four VLS unique safety precepts were then melded with all the other applicable existing safety requirements covered in the many publications and specifications governing ordnance, and ordnance systems both ashore and afloat to form the total system safety design. The direct and detailed management of this effort was assigned to members of the System Safety Engineering Group at Naval Surface Weapons Center, Dahlgren.

The results of this focused on priority effort to build safety into the VLS from conception yielded impressive results and innovative design features which allow the launcher to meet all of its operational requirements with a high degree of safety.

MAJOR SYSTEM SAFETY FEATURES

At the weapons systems level, the LAUNCH ENABLE function provides the first layer of safety by electrically isolating all missiles until authorized by the Commanding Officer or TAO. As shown in Figure 6, this function through serial electro-mechanical relays in each LSEQ physically interrupts the critical missile functions listed within the schematic for each missile type. Launch Enable is controlled by key activated electrical switches located in CIC (primary) or at each local status panel (backup). The Launch Enable function is provided at the local status panel primarily to isolate the launcher during maintenance operations and as the backup to the remote launch enable panel in CIC in the event of battle damage. When the key switch is turned, an electrical signal closes the Launch Enable relays. Closing these relays enables the electrical path to additional relays downstream. These relays are subsequently closed by additional discrete signals at the proper point in the launch sequence. Removal of Launch Enable at any point in a

launch sequence prevents launch throughout the system. By monitoring the presence or absence of this signal, VLS reports its status to each WCS. Each WCS is then able to proceed with or inhibit further missile initialization through internal interlocks in its own computer program. In the event Launch Enable is used to stop a launch in progress, both VLS and WCS can automatically initiate missile safing and shutdown routines if required.

Weapon systems level safety is also provided within the computer programs of both the WCSs and VLS LCUs. In the event of the loss of communications between WCS and VLS and failure of the redundant communications path, VLS will automatically safe and power down all missiles communicating with that WCS. Additionally, VLS or any WCS can independently initiate such safing sequences upon the detection of any abnormal launch conditions, whether they are present within the missile, the launcher or the WCS. Figure 7 illustrates the degree to which each computer program (including the missiles') performs constant message validation for all messages going across its interface(s). Beyond the normal checksum processing used in all good digital communication protocols, proper addressing and sequencing for each missile in each cell location is monitored and enforced on a message by message basis. Any discrepancy in any message is cause for rejection and up to three retries are allowed. After a third retry failure, the system declares a loss of communications and proceeds to use back up channels. If these channels aren't working properly, any or all of the elements of the weapons system will again automatically safe the missile and either select another missile or secure from launch.

Positive and safe control is maintained within the VLS through additional launcher-unique design features. Figure 8 illustrates the potentially hazardous conditions which are monitored within each cell and within the launcher along with a flow chart of where each of these conditions are reported. The functions shown under the box labeled "Damage Control" are powered continuously, even if the launcher is powered down. Since these functions are critical to the ship, they have a back up power source which automatically maintains active hazardous monitoring in the event primary power from the ship is lost.

The LCCP prioritizes and classifies each condition according to its total system impact under all operating conditions of the launcher and exercises appropriate alarms, interlocks and inhibits. In the event that an anomolous condition occurs during a missile firing, according to its particular classification, VLS may continue to launch or stop it. If it interrupts a launch, it will either initiate automatic safing routines, or with certain faults, request that an operator through manual action activate an override. Given an override command, it will allow the firing as planned. The LCCP also contains provisions to safely conduct exercise firings to ensure that only the exercise bird is launched. This allows a ship to receive and conduct its exercise under close to tactical conditions without unloading its tactical missiles. When placed in the "exercise state," an operator at the launch control unit must authorize the specific cell or cells to be fired and this authorization must agree exactly with the configuration of canister switch positions of all missiles. If it doesn't, all launch related orders are rejected and the system will not proceed into its ready alert (i.e., missile firing) mode.

Each LSEQ enforces still further designed safety features for its module and individual cells. Beyond the continuous hazards monitoring already

mentioned, the LSEQ regularly exercises BITE to detect and report any anomolous conditions occurring within its module, conducts continuous warhead identification validation as part of its inventory monitoring routine, and monitors and reports the position of all canister switches. The LSEQ also performs independent message validity checks, monitors the position of all hatches and canister dogs for proper positioning, provides automatic operation of the deluge cool down system and plenum drain system, and detects any changes in missile identification or inventory. As part of the hierachy of system interlocks, the LSEQ enforces those shown in Figure (9) prior to reporting to the LCU(s) and WCS(s) that both missile and module are ready. No ordnance events occur prior to this message and without a satisfactory report, launch operations are suspended and that particular missile is safed.

Recognizing that no design is perfect and remembering those little digits, VLS provides for safely handling the classical ordnance incidents which can occur -- namely, a dud, a misfire, a hangfire or a restrained firing. Figure (10) itemizes the abnormal launch conditions that can arise and lists the combat system response designed into the system to safely handle these circumstances. In the event that a dud or misfire (hangfires aren't applicable to VLS -- they become either misfires or restrained firings) do occur, the safest place for the suspect missile to be is within the launcher. Although there is an ability to jettison a canistered missile using the strikedown system, this would create a much more hazardous condition than keeping it safely stowed (and under constant monitoring) until it can be returned to port and removed under strictly controlled conditions.

To provide these concepts and demonstrate these features, VLS embarked on a major effort of analysis, test and independent review. Over 20 different contractor and government activities conducted more that 100 different major safety analyses on every piece of equipment or computer program in the weapons systems. More than 20 separate and independent safety panels or boards reviewed the total design for safety in the course of its development. Naval Sea Systems Command also convened a Blue Ribbon Safety Panel of senior ordnance and combat system experienced Navy Captains Chaired by a Flag Officer to specifically review VLS's readiness for deployment. It received unqualified approval.

Not relying on just analysis, VLS established a comprehensive test program to demonstrate the design. A structured sequence of tests were prescribed from the component level up to full scale flight demonstrations for each missile type and then for each combination of missile types. Permanent full system level test sites were established for each missile type and thousands of both "go" and "no go" tests were run using sophisticated simulators and inert but operationally capable missiles. Over 50 flight tests were flown from land-based test sites or from a test and evaluation ship at sea. Thousands of manhours at more than seven different facilities were dedicated to just system fault processing in order to wring out any "bugs" in the computer programs and LSEQ firmware. This testing continues today as VLS prepares for its Milestone IIIB decision.

In the final section to follow, I will identify some of the new operational and life cycle maintenance considerations of this system. After all, VLS is still only an adolescent.

KEEPING IT SAFE

All these safety features are built into the VLS design and now with the system actually deploying in active Fleet units, the challenge will be to preserve them. The disciplines set in motion during the development phase must be maintained over the operational life of the system.

Some of the less obvious safety implications of the VLS still face us and require great adjustment on the part of the Captains and Crews who will fight with VLS. There is no "blue missile" in the VLS launcher. No "blue missile" means no daily system operability testing (DSOT). If you've ever been anywhere near a ship recently, you know that the results of DSOTs are one of the major items on a Daily Report. Image the consternation of a Weapons Officer with VLS in not KNOWING that his launcher is "up" because he cannot put a test round in his system and verify that it's working end to end. This is not a small point when you consider that years of experience and daily routines with complex systems indicate that it is what's required to really know you're ready. The fundamental rule of no power in the launcher precludes this practice. With "wooden rounds" and the design of VLS to automatically select missiles, there can be no such thing as cycling the launcher to be sure it works. Beyond challenging the VLS to demonstrate its high availability and reliability, it challenges that Weapons Officer to believe in its extensive built-in tests ... not an easy request to make.

"Wooden rounds" fully encanistered in their launch cell change other standard operating procedures as well. Perhaps with harpoon having led the way, the rigorous accountability and responsibility associated with receipt inspection, custody transfer and inventory management of ordnance that can't be physically seen and positively identified by serial number won't be so traumatic. Ordnance safety has long relied on the "seeing is believing" principle not trusting in just paperwork.

Then, what of the old phrase ... "I shot an arrow in the air...". As trite as this may sound, it will take several years and lots of missile firings to overcome at least a gut-level apprehension on the part of the operators that not "pointing" a missile as on a rail launcher is really a safe thing to do. That same type of apprehension will linger for a long while over igniting missiles two decks below the main deck and believing that they will fly safely away. These are all small things certainly, but they are legitimate concerns when dealing with a new order of things and should not be lightly dismissed. Lots of little worries will raise their ugly heads when these ships with VLS are far away from Washington and the engineers who built it.

These are just a few of the new constraints and uncertainties that accompany VLS into the Fleet. To preserve the safety of the system, VLS has three CARDINAL RULES OF SAFETY that must be observed during operation (Figure (11)). If these rules are always followed, no matter what the circumstances, VLS will remain a safe and reliable system.

The first rule requires no explanation: NEVER APPLY POWER TO A MISSILE UNTIL IT IS INTENDED TO BE LAUNCHED.

Secondly, NEVER MIX SIMULATORS WITH LIVE ORDNANCE.

And lastly, VLS MUST BE MAINTAINED AND OPERATED ONLY BY TRAINED PERSONNEL USING AUTHORIZED PROCEDURES.

The second and third rules deserve some discussion.

During the course of the launcher development several very simple and sophisticated missile and computer program simulators were developed to assist in the extensive surety testing that went on. When connected to VLS, they appear in every way to be a real missile. VLS cannot distinguish these simulators from a real missile, and if they are ever connected to VLS when ANY ordnance is in the launcher, VLS will not discriminate between the simulator and the real missile. Considering the degree of automation in VLS, this can quickly lead to EXTREMELY UNSAFE conditions. This is a rule that should never be broken.

The third Cardinal rule of Safety is a little easier to understand. Because VLS is such a complex and revolutionary approach to a missile launcher, a very intensive and specialized course of instruction is required to operate it safely. Both military and civilian personnel who work with VLS undergo this extensive training and complete an individual qualification and certification program. The technical manuals for VLS contain the only approved procedures for operating, maintaining and troubleshooting this system. These procedures were tested and proven during the course of developing VLS and are the ONLY safe procedures to use. There will never be any bulletins or technotes published for VLS to avoid any question of ambiguous procedures. This regimentation is absolutely essential for safe operation.

There are a great many challenges still to come for this new system. this paper has focused on the need to meet them safely. Safety was only one of a number of major program objectives for VLS... but it was the NUMBER ONE objective, and in the words of Robert Frost "...that has made all the difference."

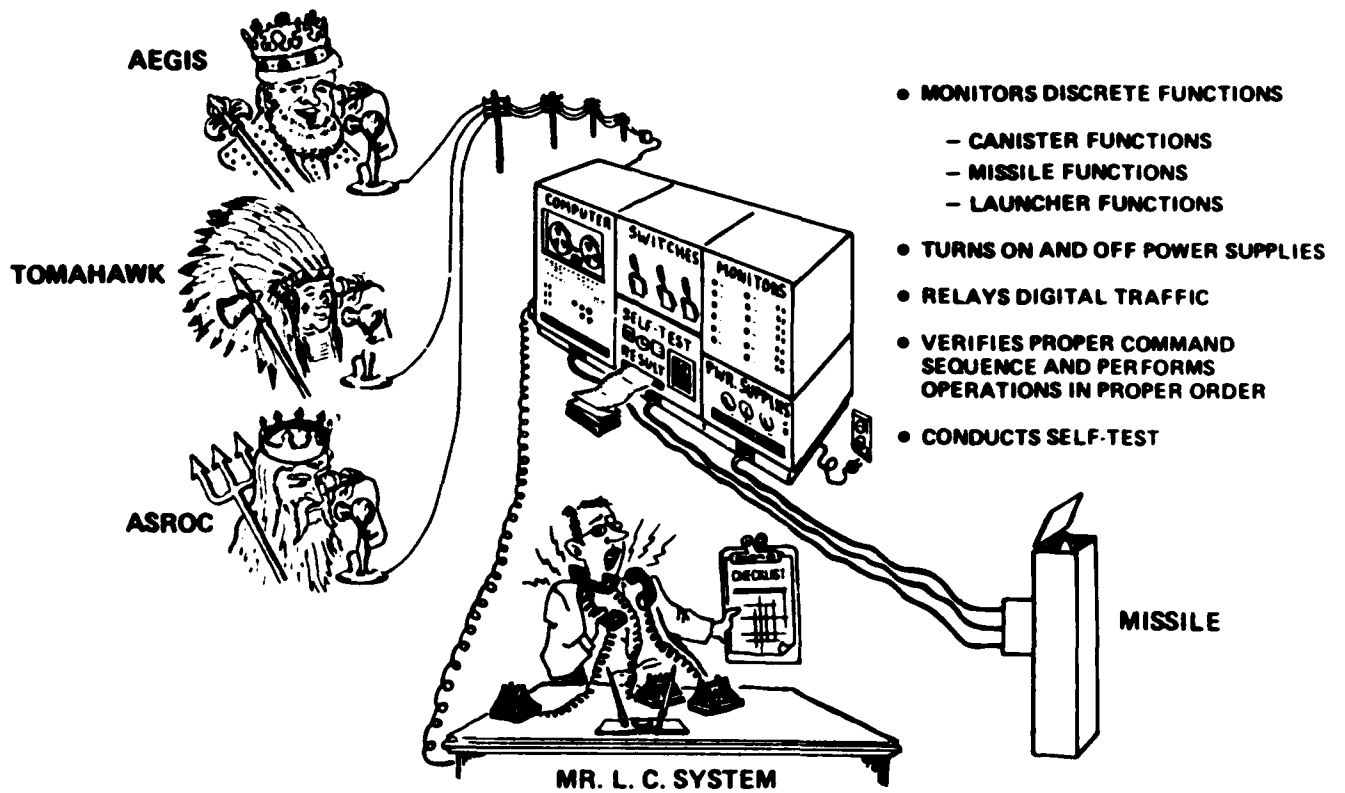


Figure 1. VLS Architecture

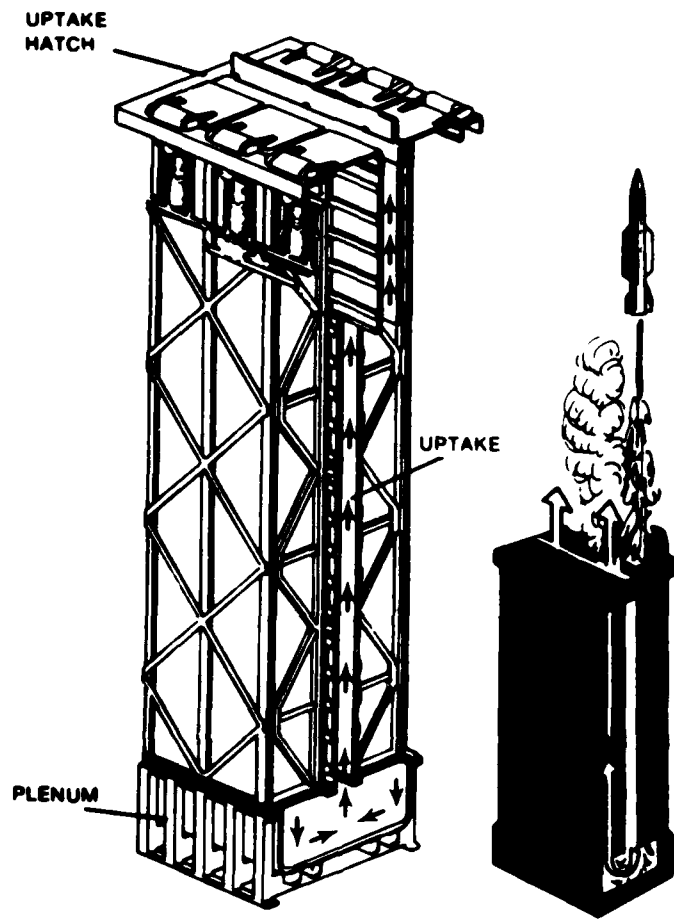


Figure 3. VLS Gas Management System

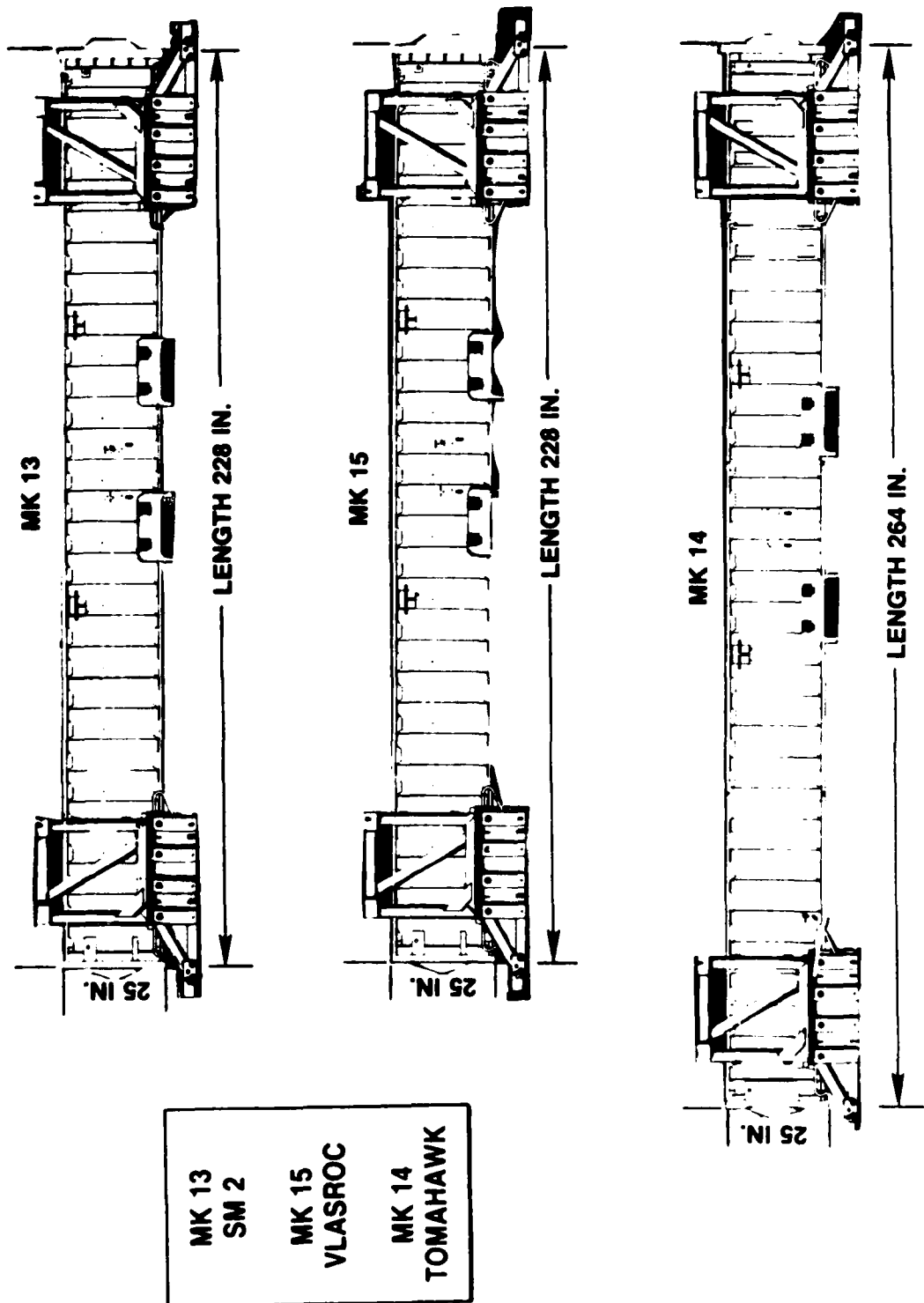


Figure 4. V.I.S. Canisters

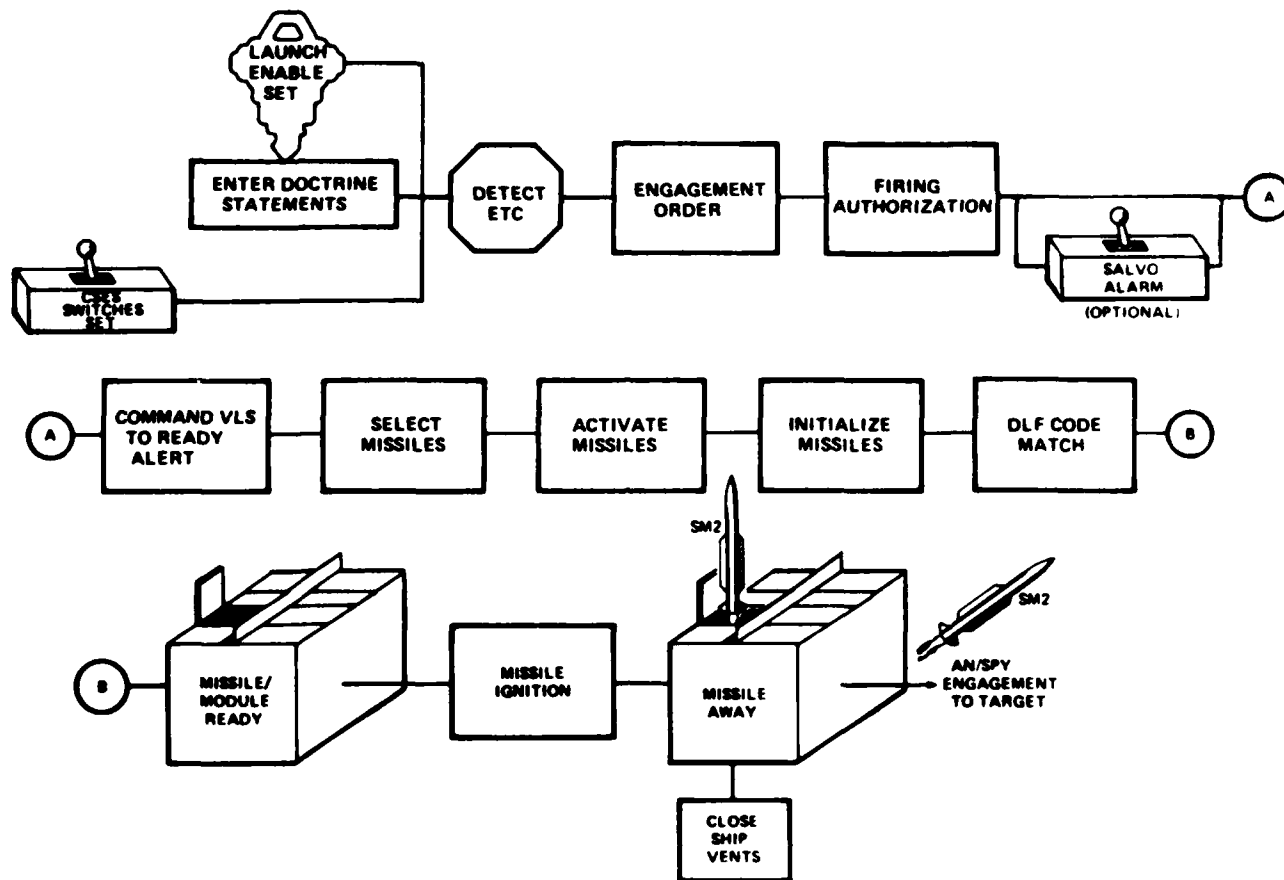


Figure 5. AAW Launch Sequence

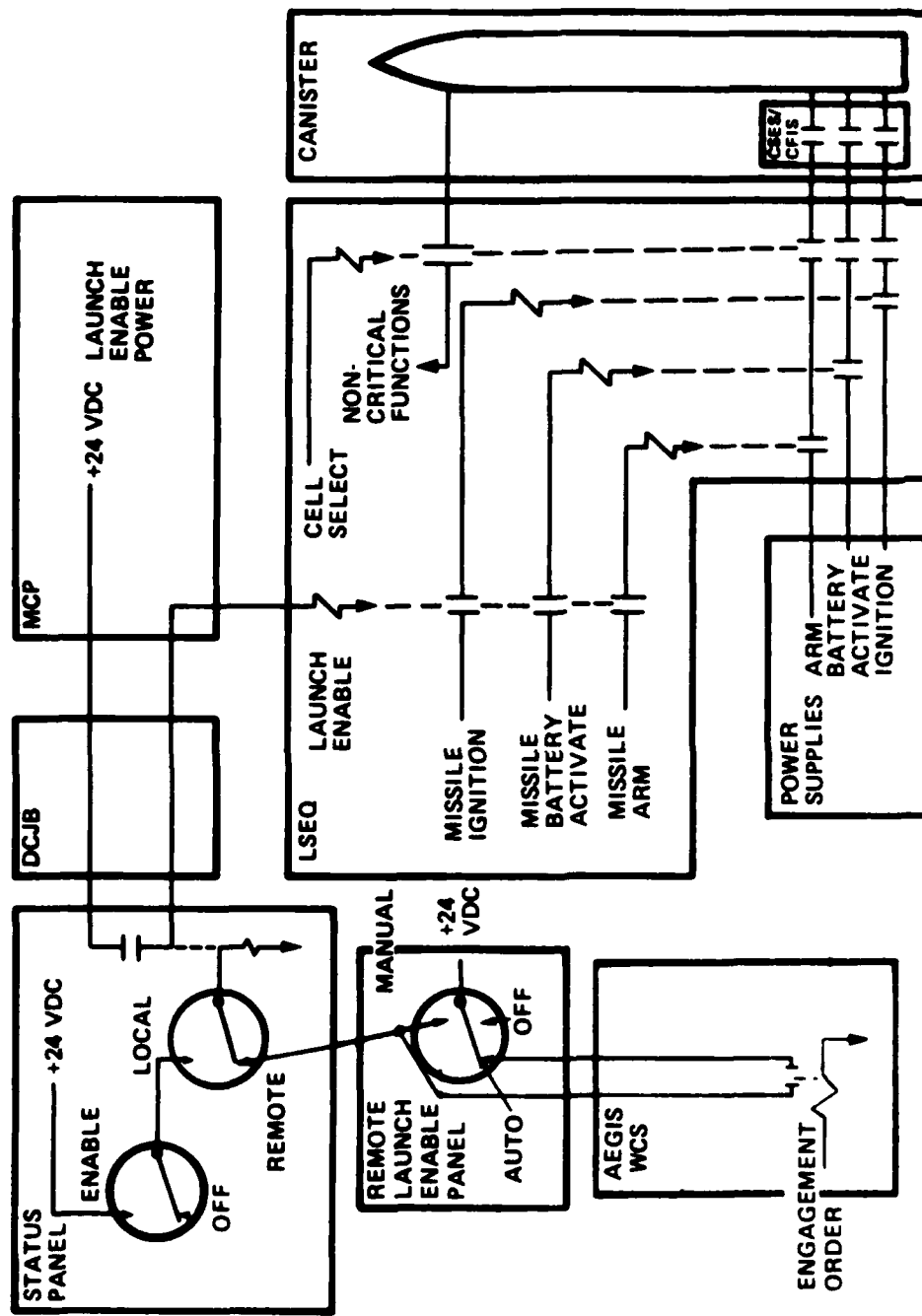


Figure 6. Launch Enable Safety

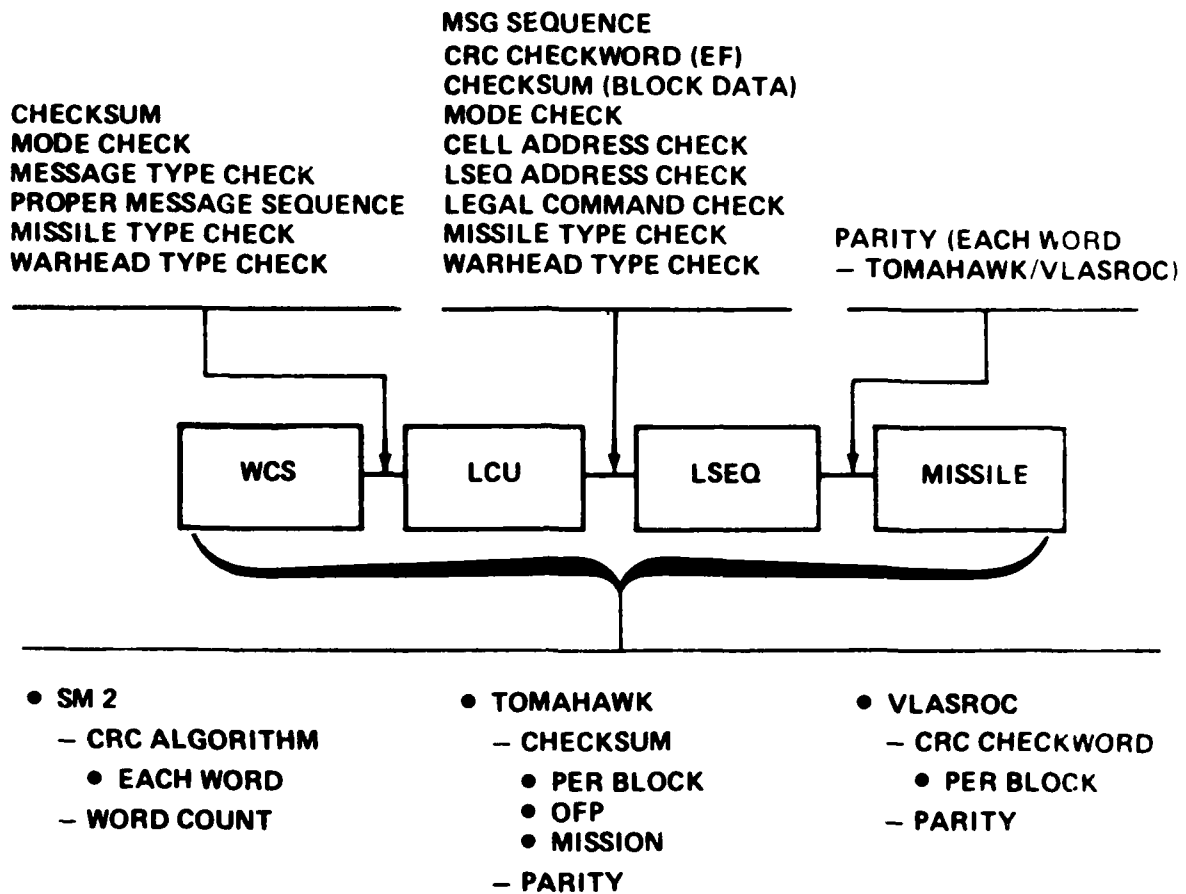


Figure 7. Message Validity Checks

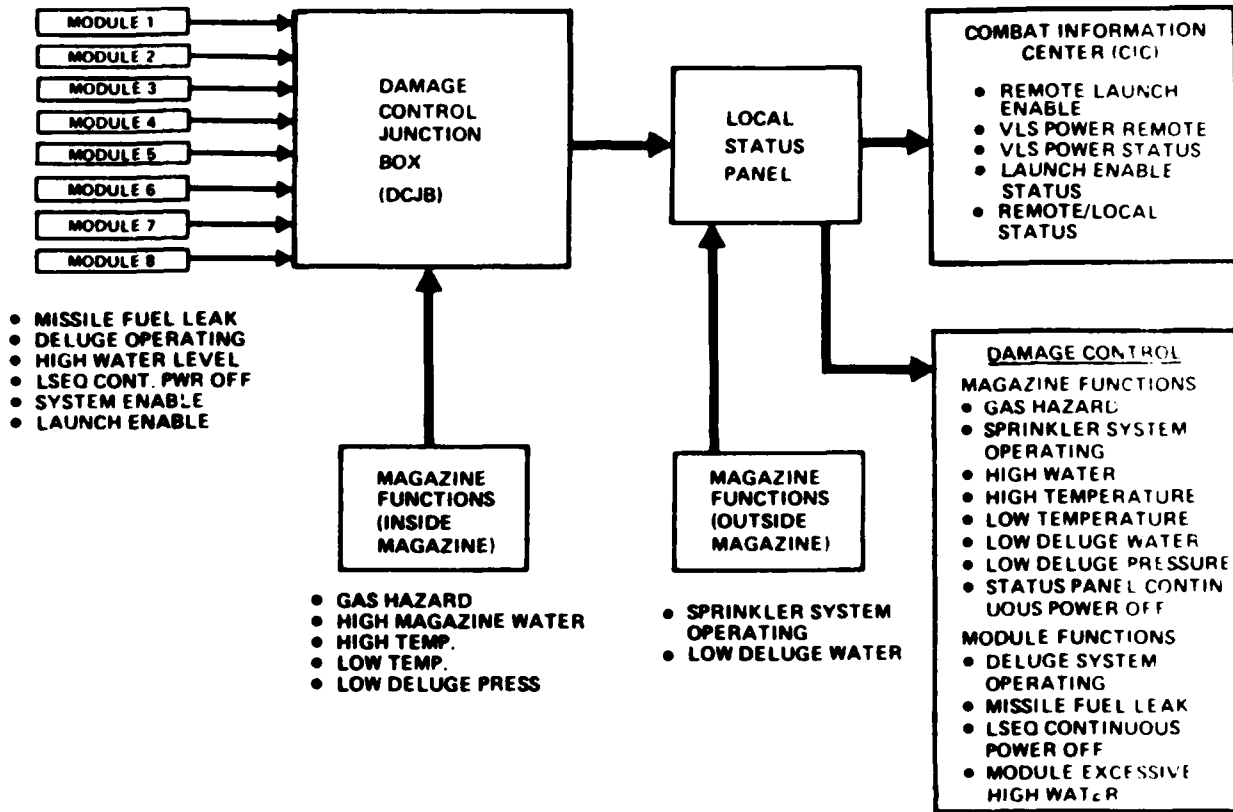


Figure 8. VLS Hazards and Status Monitoring

MISSILE/MODULE READY

- LAUNCHER HATCH OPEN
(2 MONITORS)
- UPTAKE HATCH OPEN
- LAUNCHER READY
- MISSILE READY

IGNITION

- LAUNCHER HATCH OPEN
(2 MONITORS)
- UPTAKE HATCH OPEN
- LAUNCHER READY
- MISSILE READY
- LAUNCHER HATCH CLOSURE
INHIBITED
- LAUNCH RATES SATISFIED
- LAUNCH PRIORITY SATISFIED

Figure 9. VLS Launch Sequence Interlocks

	<u>CONDITION</u>	<u>COMBAT SYSTEM RESPONSE</u>
DUD	<ul style="list-style-type: none"> • BATTERY ACTIVATE SENT TO MISSILE • MISSILE NOT LAUNCHED 	<ul style="list-style-type: none"> • VLS AND WCS SAFE MISSILE • CELL HATCH CLOSED • DUD CELL UNAVAILABLE • NOT OVERRIDEABLE FOR DUD CELL
MISFIRE	<ul style="list-style-type: none"> • IGNITION COMMAND SENT TO MISSILE • MISSILE DOES NOT IGNITE 	<ul style="list-style-type: none"> • VLS AND WCS SAFE MISSILE (MISSILE NOW RESTRAINED) • CELL HATCH CLOSED • MODULE (8 CELLS) UNAVAILABLE • FAULT OVERRIDEABLE FOR OTHER 7 CELLS
HANGFIRE	<ul style="list-style-type: none"> • IGNITION COMMAND SENT TO MISSILE • DELAYED IGNITION • MISSILE AWAY 	<ul style="list-style-type: none"> • NOT APPLICABLE FOR VLS – SYSTEM MAINTAINS POSITIVE CONTROL (RESTRAINT) FOR DELAYED IGNITION
RESTRAINED FIRING	<ul style="list-style-type: none"> • MISSILE IGNITION • NO MISSILE AWAY 	<ul style="list-style-type: none"> • LAUNCHER DELUGE MISSILE FOR 90 SECONDS • MODULE (8 CELLS) UNAVAILABLE • FAULT NOT OVERRIDEABLE

Figure 10. Abnormal Launch Conditions

- **MAINTENANCE AND OPERATION ONLY BY TRAINED PERSONNEL USING AUTHORIZED PROCEDURES**
- **DEAD ELECTRICAL MISSILE INTERFACE UNTIL INTENT TO LAUNCH**
- **NO MIX OF ORDNANCE AND SIMULATORS**

Figure 11. Cardinal Rules of VLS Safety