32-Pad Launch Control System

Employing Novel Features
and
Expandable Components

National Association of Rocketry
Research & Development Report

by

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SUMMARY

This NAR R&D report describes the concept, design, and construction of a complete 32-pad launch control system developed for the Monroe Astronautical Rocket Society (MARS), NAR Section #136 in Rochester, NY. The project balances a variety of important goals — such as safety, reliability, ruggedness, and ease of use — as well as the overall cost. The system includes all components for an expandable range layout.

The equipment employs several innovative features which were designed to solve common launch system limitations:

- The main control console uses a digital rotary encoder to select the pad. This eliminates the accidental launching of multiple rockets with the typical array of toggle switches, and it solves the problem of finding a 32-position mechanical switch. A reliable digital control circuit replaces the mechanical switches for long-life operation.
- The main control console gives visual continuity indication for all pads simultaneously. There is no need to select the pad to check the igniter. This feature allows for faster operation on a busy rocket range.
- Each pad control box incorporates a high-current relay with the option of adding a local pad battery at any launch pad (for clustering, or distant pads). All pad boxes are interchangeable — for model rocket pads, high-impulse pads, or "away cells" — allowing the widest variety of range layouts using the same equipment.
- Each pad control box has a novel continuity circuit which produces a variable pitch tone to indicate igniter quality. A good (low-resistance) igniter gives a higher frequency tone, and poor (higher resistance) igniter gives a lower frequency tone. Problems such as weak igniters or dirty clips are audible both at the pad and at the main controller.
- The pad boxes have several safety features: 3-way toggle switch for TEST-OFF-ARMED modes; a pulsing tone when in the ARMED position; and a warning tone for "stuck relay" when in the TEST position.
- The cost of cabling is greatly reduced by using a single pair of wires for both the launch signal to a pad and the continuity signal from a pad. A third wire is used only when supplying power from a centrally-located battery; in this case, low-cost standard outdoor power cords are used.

Detailed design information for all system components is included in this report. The appendices contain schematic diagrams, circuit board layout drawing, parts lists, and vendor addresses, enabling others to reproduce the whole system.

This project required significant effort by the authors over a 6-month period to design, build, and test the system. Much time was spent locating quality low-cost parts, and modifying the design to use these parts, but maintain ruggedness and reliability. Many portions of the construction effort were shared by several members of the MARS section.

The new MARS launch system has been used successfully at recent launches, including this year's National Sport Launch at Geneseo, NY with over 600 flights on the 4th of July weekend.

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1.0 INTRODUCTION

1.1 Project Concept

To respond to the growing number of high-impulse flyers, the MARS club (NAR section #136, Rochester, NY) needed to build a new launch system capable of safely supporting both their local launches and larger events. Up to that point, the club used a variety of smaller systems, with Tripoli Western NY helping out with equipment at the high-impulse sport launches.

At the end of 1996, MARS formed a Launch System committee to design a reliable, rugged launch control system, and to build it in phases to test at upcoming launches. Later, the system would be expanded to support the growing interest in sponsoring a national event on the 4th of July weekend. A budget of $500 was set for the basic 16-pad system, with a goal of $1000 as the cap for the full 32-pad system.

The project began with a discussion of current launch controller designs and their limitations. The author had built smaller systems over the years, and based many of the new concepts on his experiences (both good and bad!) with those designs. Rich Savory (NAR 69199), an electronic repair technician, volunteered significantly with design ideas and overall construction. Likewise, John Viggiano offered his thoughts based on years of experience with a variety of club system.

The committee discussed many options over a period of several weeks. The results were a set of requirements for the "ultimate" system, and a series of trade-offs necessary to get the job done.

1.2 Project Goals

The following list of features were compiled as a basis for the launch system design.

General Stuff

The system will consist of a main controller box (at the range table) with the following features:

- A safety key with three positions: OFF (allowing key removal), TEST, and ARMED.
- A large, red firing button (at least 1/2" dia) with a protective cover or recessed button.
- A rotary knob (at least 1" dia) with detented stop positions to select 16 pads (expandable to 32).
- Bright LED indicators (green) to show continuity status at each of the pads simultaneously.
- Bright LED indicators (red) to show the currently selected pad (all others remain off).
- Optional: a black pushbutton to test continuity with an audible tone for the selected pad.
- Easily readable labels for the pad numbers, connectors, and all functions on the controller.

Each pad will have a pad controller box with the following:

- A switch to completely disable the power to the box and igniter leads under all circumstances.
- A switch (or pushbutton) to test the continuity of the igniter, giving an audible tone if good.
- A pair of connection points for easily detachable igniter leads (banana jacks/binding posts).
- A connector (or hardwired cable, if too costly) for the signal & power from the main controller.
- A connector for a local pad battery if the controller is significantly far from the main battery.
- Easily readable labels for all functions and connections.

The pads will be located (nominally) at the following distances (expandable to 32 pads):

- 5 - 10 pads at 25ft - 50ft.
- 5 - 20 pads at 100ft - 200ft (with right & left banks of 5 - 10).
- Minimum of 2 pads at 300ft - 500ft (K/L/M away cells).

- Distribution boxes will be used to reduce the length of high-current cables.
- All enclosures & cabling will be brightly colored to reduce the chance of damage from tripping.
- All battery connections will be designed to easily attach various types of battery packs.
- Batteries will be chosen to operate for a full day's use under all weather conditions.
- Batteries will be purchased with sufficient rechargers to handle all batteries overnight.

Reliability & Safety

- The system must work with a range of battery types and voltages (lead-acid and NiCad), with a nominal value of 12V, but cover a range of battery charge conditions (10 - 15 volts) without damage or mis-operation.
- The system must work for all types of igniters, supplying sufficient current to ignite them.
- The continuity test circuit must be safe for all types of igniters.
- An audible detector must warn of shorted relay contacts (live circuit) at relayer pad controllers.
- The main controller will have a safety key that is removable only when the controller is off.
- The controller must not allow more than one rocket to launch at the same time. "Drag Races" will be allowed only by igniting more than one rocket from a single pad controller (same as clustering).

Ruggedness

- All enclosures and cables will withstand outdoor use in all weather conditions.
- All enclosures and cables will hold up to dropping and "banging around in storage".
- All connectors will not be damaged if pulled on by tripping over cables.
- All components and connections in the high-current path will handle at least 20 amps continuous, and 40 amps for up to 5-10 seconds. Overcurrent will not damage the equipment (use a thermal breaker).

Simplicity & Flexibility

- The system must be easy to use, with simple straightforward controls.
- If possible within cost, all pad controllers should be interchangeable between the model rocket pads and the farther pads. This will give the maximum number of possible range layouts, and will allow swapping pad controllers if one fails.
- The distribution boxes will "pass through" all unused signals to allow "daisy chaining" the signal cables. This will reduce the length of the large signal cables, and will allow various range layouts.

1.3 Design Trade-offs

To realize these goals, very few compromises were required to stay within cost and available parts. The only trade-offs that were required are listed below:

- Power cords and panel-mount AC receptacles would be used for the high-current connections. (COST).
- Non-outdoor cables would be used for the signal connections to the high-impulse banks of pads (COST).
- A short, single-ended power cord would be attached to each pad box. (Female AC panel-mount receptacles could not be located).

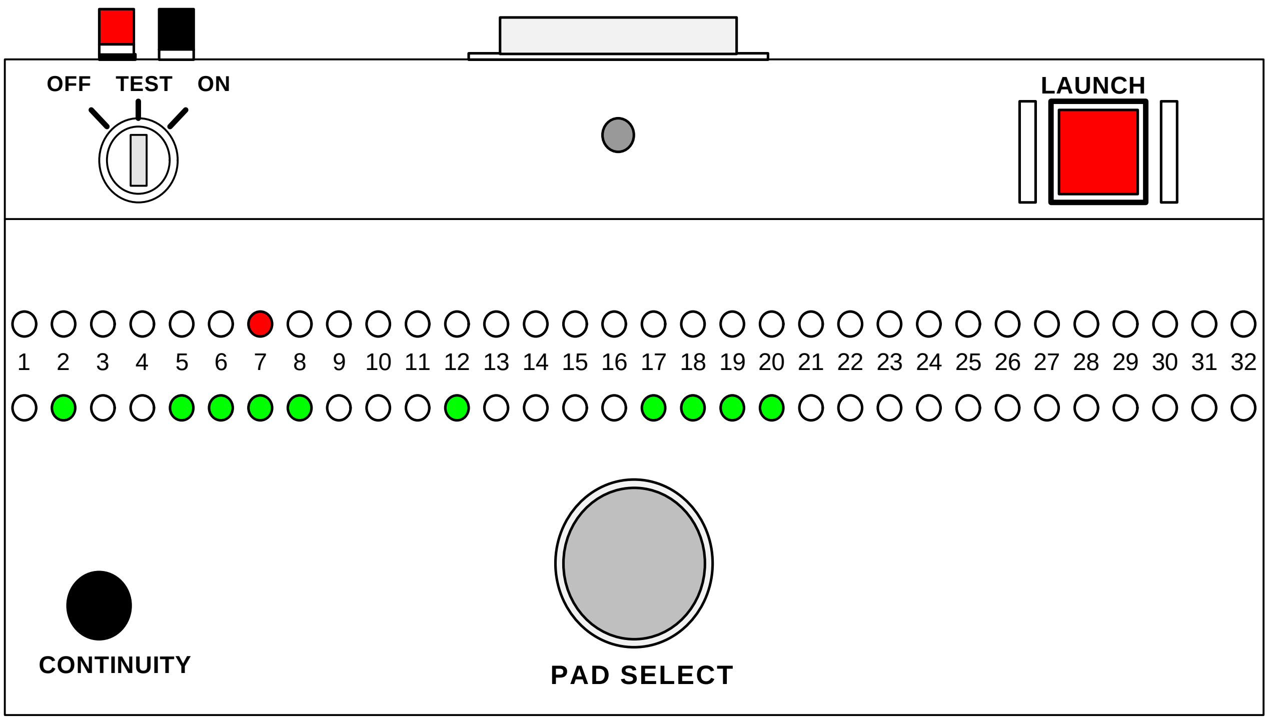
All other goals of the system were incorporated in the design and construction.

2.0 LAUNCH SYSTEM DESIGN

The following sections describe the functionality of each component in the launch system. The diagrams contain enough detail for the reader to become familiar with the design. For complete schematics, see Appendix A.

2.1 Main Controller

The heart of the system is the Main Controller console. In contrast to the typical, multi-pad console, the front-end has a simple set of controls and indicators. However, a more complex digital circuit and relay drivers are needed to control the pad selection, launch signal, and continuity detection.



Approximate Layout of the Main Control Console Front Panel.

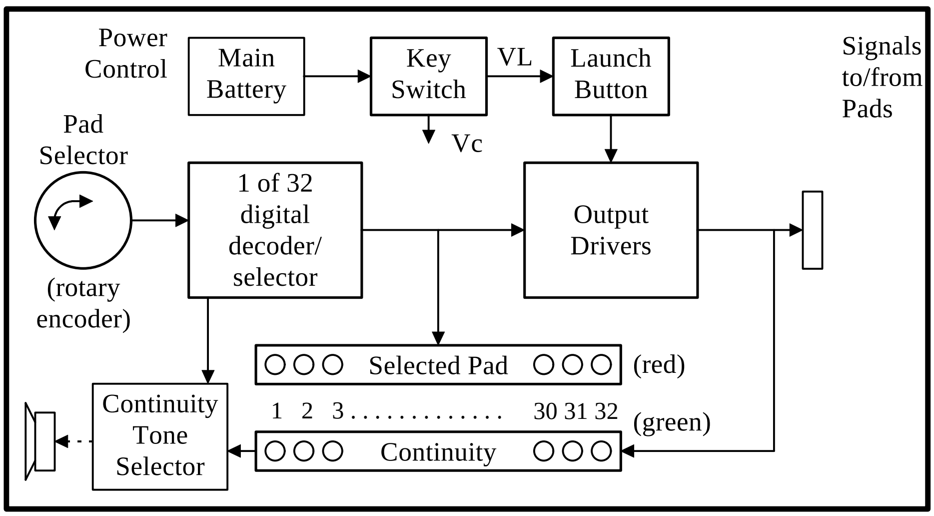
The internal design of the Main Controller uses low-cost 12V CMOS logic and discrete components to implement the pad selection and driving circuitry. The main sections of the circuit are shown in the diagram on the next page, and are described below.

The rotary encoder is simply a pair of switches with a slight offset angle. These are commonly used as controls for volume or tuning on car stereos, etc. When rotated in one direction, switch #1 leads switch #2; when rotated in the opposite direction, switch #2 leads switch #1. With this action, the decoder circuit counts the pulses, either up or down, and stores this number (1 through 32). The selector circuit takes this digital value and selects one of 32 outputs to drive the rest of the circuitry.

The output drivers take the low-current logic signal and supply enough current to switch the selected pad relay through the total length of cabling to the pad.

The same pad-selection signals are used to switch 1 of 32 red LEDs to indicate the currently selected pad. These are extremely bright LEDs which can be seen even in direct sunlight. Also, the pad-selection signals choose the continuity tone from the selected pad to drive the speaker. The continuity button must be pressed to hear this tone.

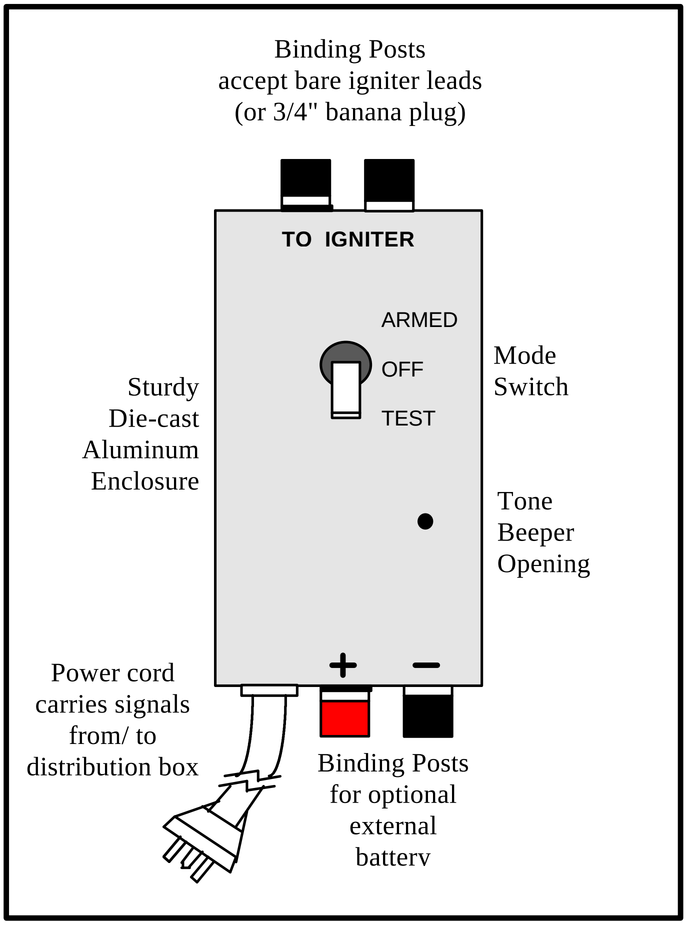
Each pad has a green LED which shows if a continuity tone is coming from the pad. The tone signal is very small (less than 0.3 volts) and is sent on the same wire as the launch signal. This low-level voltage is blocked within each pad box to isolate it from driving the relay coil. The continuity status of all pads are shown simultaneously.



Main Control Console Block Diagram

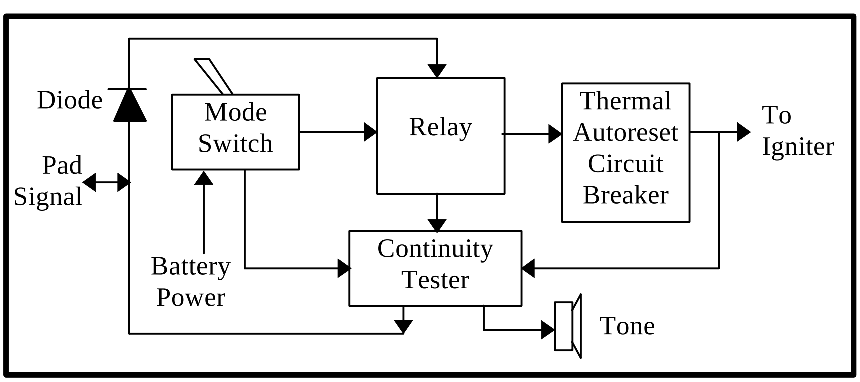
2.2 Pad Boxes

Each pad requires a Pad Control Box to switch the igniter current and generate the continuity test tone. A 3-way toggle switch has become fairly standard for many rocket clubs' launch systems: when in the center position, the pad is safe and all power is off; when switched down (away from the igniter terminals) only the continuity test circuit is enabled; and when switch up (toward the igniter terminals) the pad is armed and ready.



Pad Box Front View

The basic components of the Pad Boxes are shown in the following diagram and discussed on the next page.



Pad Control Box Basic Components

The battery power may be supplied from a central battery or from a battery connected directly to the pad box. This allows the most flexibility in range layout options, and makes it easy to add a battery for clustering.

The power to the igniter's high-current path is blocked by the mode switch when in either the TEST and OFF positions. The power to the continuity test circuit is only disconnected when in the OFF position. This requires a DPDT on-off-on switch.

The pad signal requires only two wires to send both the launch signal to the pad and the continuity from the pad. This saves in both the cabling and connectors throughout the system. This novel approach works by making use of the typical 0.7V forward bias required for current to flow through the diode. When a 12-volt signal is present, the diode conducts and the relay coil sees about 11.3V (the particular relays chosen will operate properly down to 6V). When the 0.3-volt continuity tone is being sent back to the main controller, the diode voltage is well below the 0.7v required to conduct.

The relay is a standard automotive type capable of 30 amps. When the launch signal is sent to the relay coil, it makes the high-current connection from the battery power to the igniter. The circuit breaker is rated at 20 amps continuous, and will open the circuit if more than 20 amps is used for over 5-10 seconds. This protects against shorted igniter clips wasting battery energy and overheating the circuit. The breaker will automatically reset once power is removed for about 10-15 seconds.

When the launch signal is NOT present, the continuity circuit senses the igniter resistance to produce the continuity tone. A small sensing current of less 0.5mA (safe for all types of igniters) is sent through the igniter and the resulting voltage is amplified about 1000 times. This voltage is used to control the frequency of a tone generator. The resulting tone is about 1KHz for a typical 0.5-ohm igniter, down to about 100Hz for a 5-Ohm poor igniter. Various types of igniters actually produce different frequency tones because of their different values of resistance! This is very helpful (both at the pad and at the main controller) when connecting the igniter, or when trying to determine the cause of a misfire. A typical continuity circuit will give the same tone for all but the worst connections.

When in TEST mode, the tone is on continuously to indicate safe voltage at the igniter. When in the ARMED mode, the tone becomes pulse on/off to indicate that the pad will fire when it receives the launch signal. An added feature of the pad box is a check for a faulty relay (such as welded contacts). When in the TEST mode, a pulsed tone (as if ARMED) will indicate that the relay has failed in the closed position. If this happens, switching to ARMED will launch the rocket! This is a very important unique safety feature of this system.

All high-current wiring in the pad box is done with heavy-duty wire and connections. However, the thermal circuit breaker gives an additional level of protection against burning out the circuit (added cost is $1 per box). This feature was tested thoroughly without being able to damage the components, even with the a dead short across the igniter terminals. At the same time, over 40 amps were measured for short bursts.

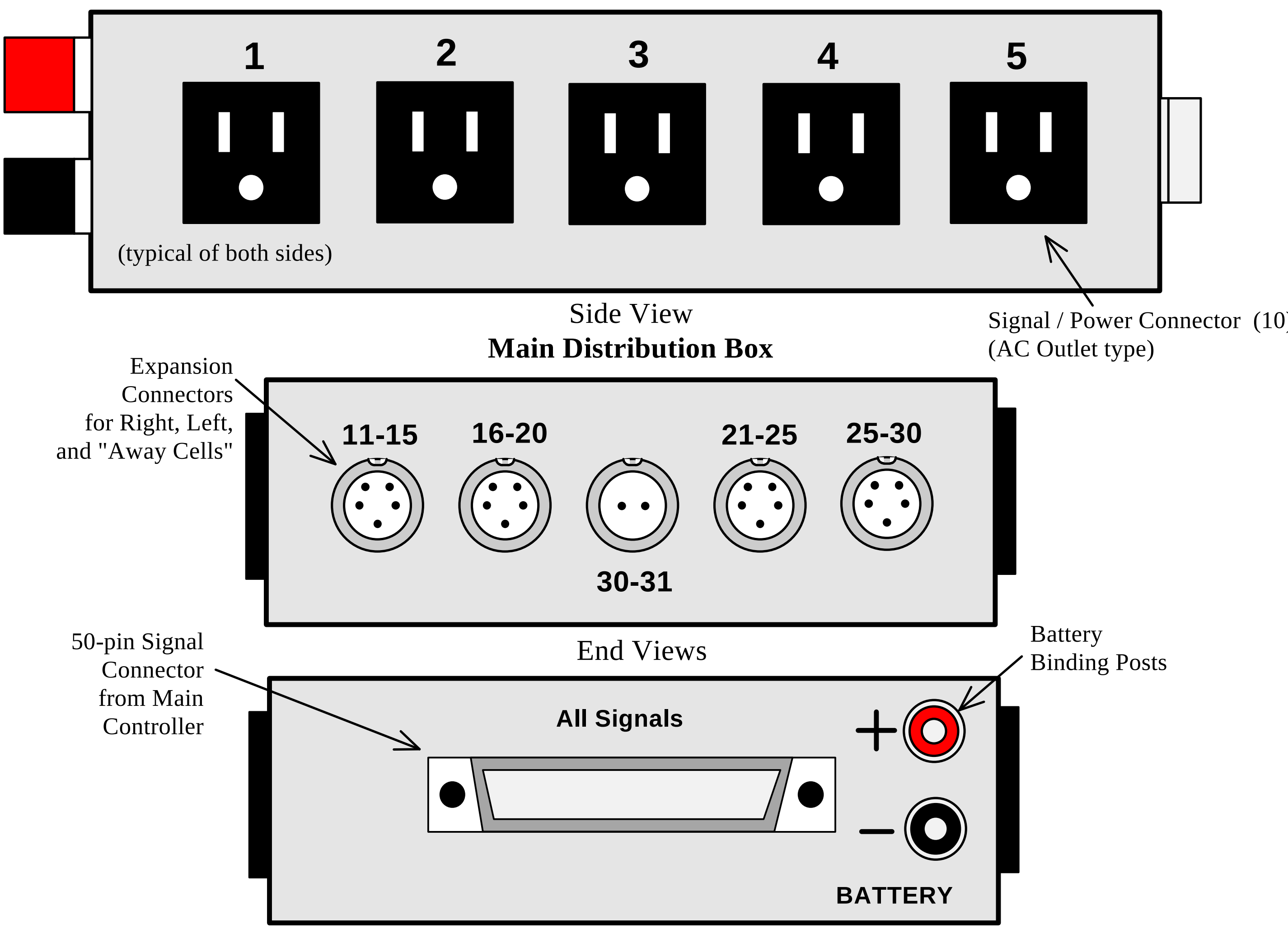
2.3 Distribution Boxes

All signals from the Main Control Console are sent to a Main Distribution Box before going to the Pad Boxes. This first distribution box connects directly to up to 10 pads at 50 feet (for low-impulse model rockets), and has circular connectors to expand the system to the full 32 pad boxes.

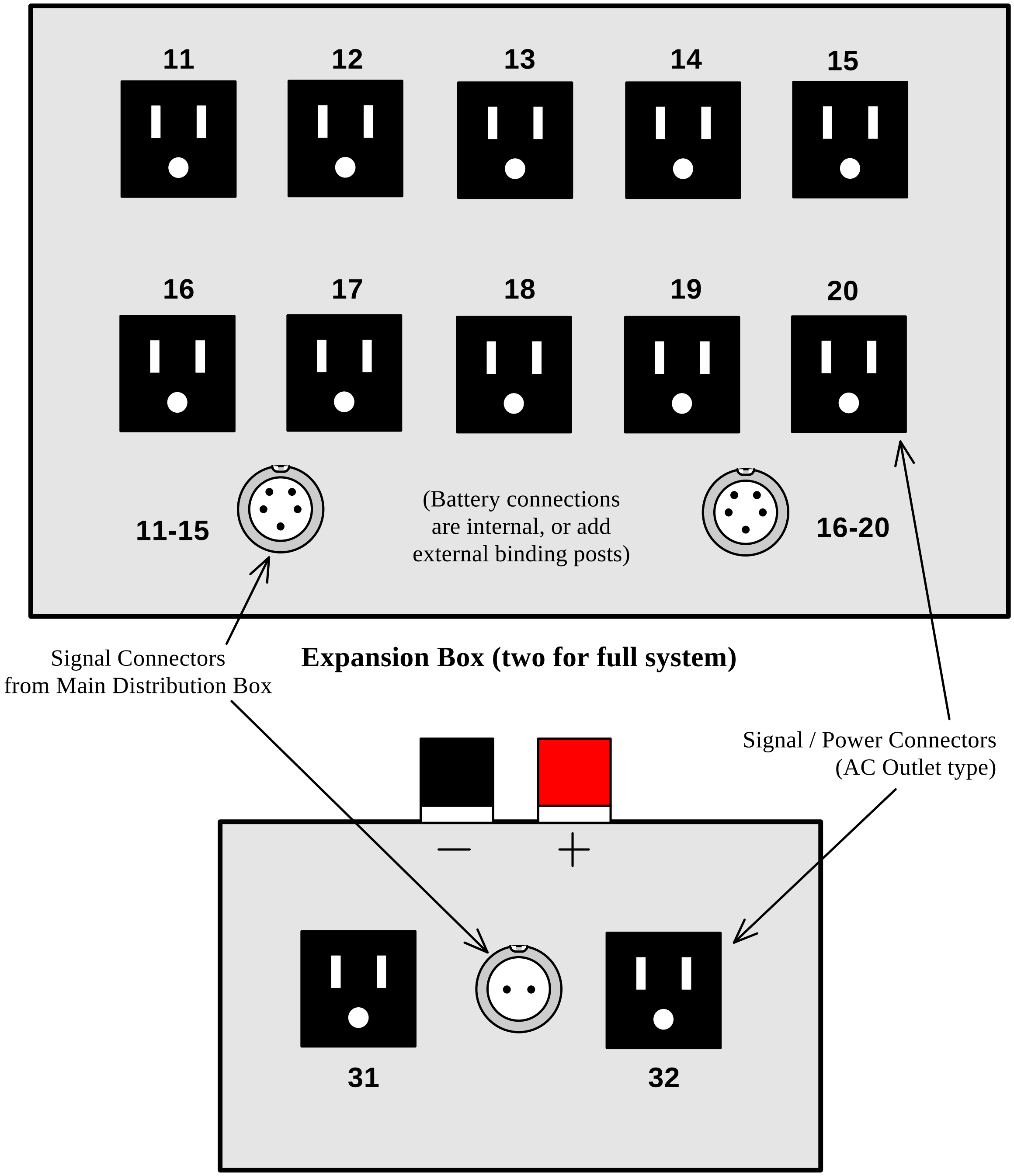
Each of the expansion connectors carries 5 pad signals. The Secondary Distribution boxes accept one or two 6-conductor expansion cables, giving a maximum of 10 pad boxes each. In a practical range layout, these Secondary boxes are used for right and left banks of high-impulse pads at about 250ft. They could also be used to expand the number of model rocket pads.

To complete the 32-pad arrangement, the last two pad signals are sent through a 2-pad expansion connector. These positions would normally be used for two "away cells" for complex K or L/M high-impulse pads at 300-500ft (or greater).

All of the distribution boxes are terminated with standard panel-mount AC outlets. This allows the system to connect pad boxes at any distance from the distribution boxes using standard AC power cords.



Main Distribution Box



Expansion Box (two for full system)

2-Pad "Away Cell" Expansion Box

2.4 Cabling

As with any multi-pad launch control system, the cabling is a major factor in the overall cost and complexity. In this system, several decisions were made for interconnections that greatly reduced the cost.

First, the Main Control Console is connected to the Main Distribution Box via a 50-foot 50-conductor SCSI (computer peripheral) cable. This sturdy cable assembly comes with pre-molded 50-pin "Centronics type" connectors on both ends. An equivalent cable made from separately purchased wire and connectors would cost nearly $200. The author located a surplus supplier with this cable in stock for $19! (See Appendix C). Since this cable only carries low-current signals (no igniter power), the 26 AWG conductors are sufficient. Also, the mating panel-mount connectors were low-cost and easily available.
This 50-wire cable has more than enough conductors for the system (32 + ground are needed).

Secondly, the Main Distribution Box is connected to each of the Expansion Boxes using low-cost 6-wire communication cable (at 3.5 cents/foot). As with the main cable, these conductors are for low-current signals, requiring only 24 AWG. The connectors chosen for these 5-pad interconnect cables is a standard "MIC" connector, intended for interconnecting microphone. They are sturdy metallic connectors with positive screw-on connections, and are readily available at low cost for both cable and panel mount. This choice was at least ten times cheaper than using military-type circular plastic connectors.
The compromise, though, is that the cable is gray and not very visible on the field.

Lastly, the high-current cabling uses standard AC power cords, the bright orange type intended for outdoor use. These are low-cost sturdy 16 AWG wires (or better) and eliminate the need for expensive connectors (they are already molded onto the cords). To expand the system, or to increase stand-off distances, the power cords may extended by plugging them end-to-end.

When using an optional battery at a pad, the power cord could be a much smaller gauge, since only the low-current signal is sent through the cable. To make this easier, the pad boxes are wired with the 12V power on the AC ground pin so that a 2-wire extension cord (without ground) could be used. However, if the system is set up with a combination of central batteries and local pad batteries using 3-wire AC cords, the two power source should not be connected together (battery voltages are slightly different). In this case, a standard AC grounding adapter is used to isolate the two batteries by connecting an adapter in-line with the plug at the pads which use local batteries.

2.5 Batteries

The system requires at least one battery at the Main Controller and one battery at the Main Distribution box for a simple range layout. The battery at the Main Controller does not need to supply as much current as the igniter power battery, so most 12V sources will work (<1 amp). The batteries which supply igniter current (at the distribution boxes or direct to pad boxes) need to supply sufficient current for the types of igniter being used.

For a complete 32-pad range layout, a minimum of five batteries are required: at the Main Controller, at the Main Distribution box, at each of the two Expansion boxes (right and left banks), and at the 2-pad "away cell" box.

A surplus source for new 10Amp-hour "gelcell" 12V batteries was located during the search for low-price parts. Normally, the RC hobby batteries of this type sell for around $30, and sealed lead-acid car batteries are as expensive and much bulkier. The surplus batteries were originally intended for starting a lawn tractor, and were purchased at $15 each plus $2 shipping each. Six were purchased in order to have an extra at the field.

Because the Pad Boxes can use a range of battery voltages from about 6-15 volts, other batteries could be used, such as NiCd packs. However, we chose not to use these due to the lower life cycle of NiCd batteries (recharge "memory"), and the expense of high-current types.

3.0 LAUNCH SYSTEM CONSTRUCTION

3.1 Main Control Console

To build the digital control circuit for the Main Controller, it was necessary to design a custom printed circuit board. Hand-wiring the circuitry was considered, but the 1700 connections would make it a difficult (and unreliable) task! Computer-aided design software was used to enter the schematic and layout the circuit board drawing. The software package (EZ-BOARD) runs under Windows and specifically designed for circuit board layout.

Originally, we had planned to etch the circuit board ourselves, but the size would not allow us to reliably do this (even with a single-sided copper board). The major cost overrun in the project was for the commercially-made blank circuit board for the Main Controller ($120 for one, and an extra was made). However, the quality was worth the expense.

The fabrication of the physical enclosure was done by MARS member Ed Norris (NAR 33196). He is a senior machinist and made the enclosure from stainless steel sheet stock using laser-cutting and auto-bending equipment. The end result is a professional piece of equipment with a perfect match to the drawing supplied by the author.

The author did the component insertion and soldering for this large circuit board, and all the internal wiring for the Main Controller. All circuitry had been prototyped and tested before designing the board layout, so this complex board ended up working the first time with only a minor modification.

See the Appendices for complete schematics, circuit board artwork, and parts lists.

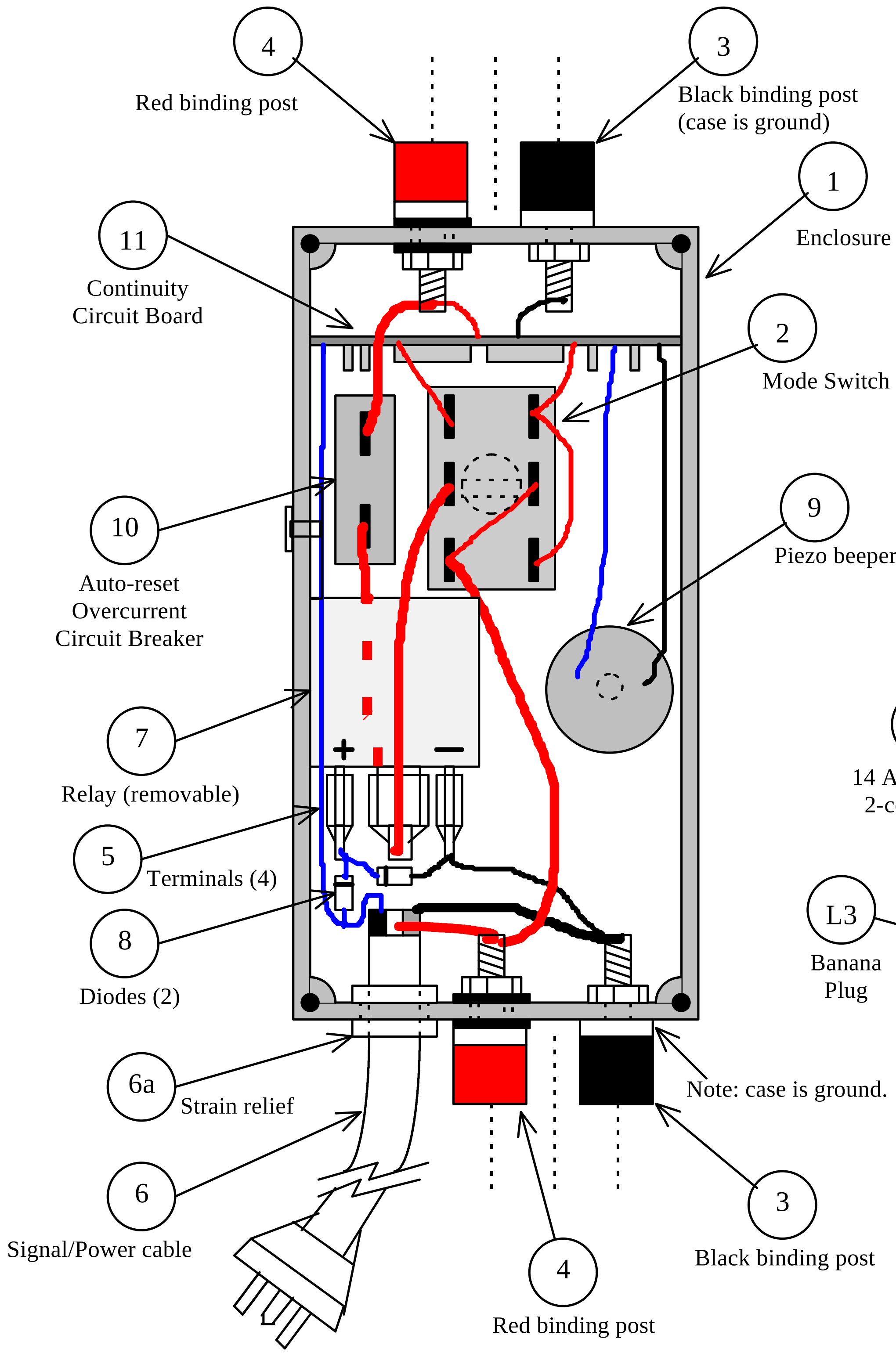
3.2 Pad Control Boxes

The assembly of the Pad Boxes was done by the authors and MARS member Rich Savory (NAR 69199). An initial set of 10 were built to test at the first MARS launch in the spring of 1997. A second set of 14 were built for a larger test later in the spring. A final set of 8 (to complete the full 32-pad system) was built by the authors for their personal use and loaned to MARS for use at NYPOWER/NSL on the 4th of July weekend. By dividing the effort into three building sessions over a three-month period, the daunting task was made a little easier to accomplish.

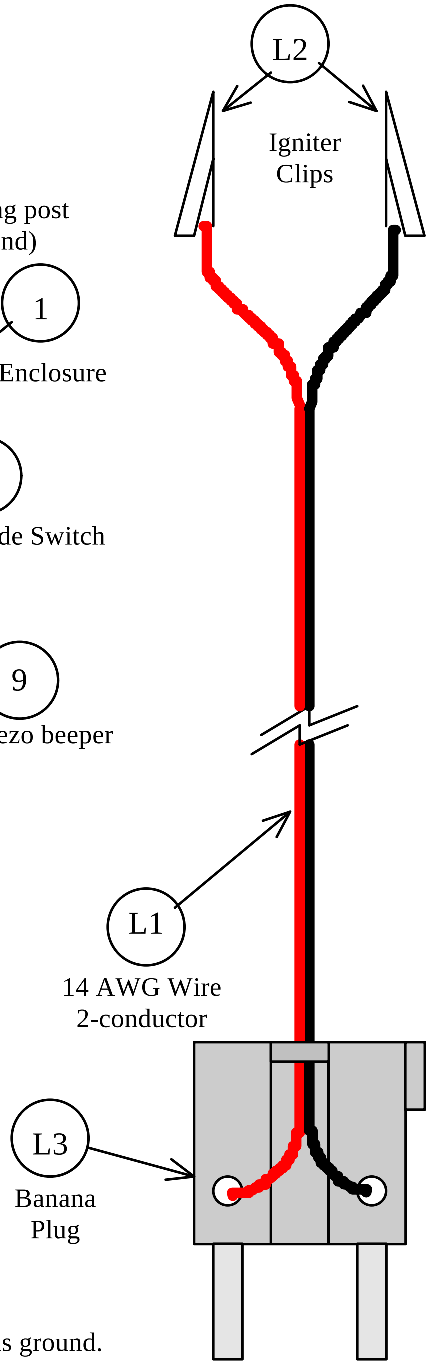
The die-case aluminum enclosures for the Pad Boxes are normally very expensive if purchased through standard electrical suppliers ($12-15 each). The author located a surplus source for these at $3.50 each. This was a major factor in producing a rugged system without plastic cases. However, machining the various openings was more difficult (18 were done by the authors, 14 were done by Ed Norris).

The continuity tester for the Pad Boxes was designed onto a small circuit board. The bare boards were etched by the authors for all 32 Pad Boxes. Half of the assembly was done by the authors and half was done by Rich Savory.

The final wiring and assembly of all parts into the enclosures took around 30-40 minutes each. This task was more difficult than expected, and a larger box would have made it much easier.



Pad Box Assembly (actual size)

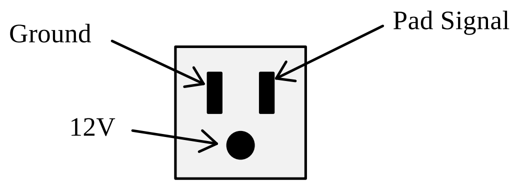


Igniter Lead Assembly

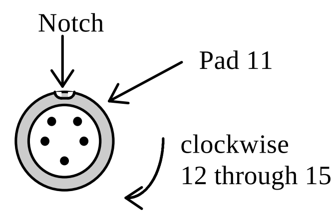
3.3 Distribution Boxes

Of all the components in the system, the distribution boxes were the easiest to construct. The incoming signals are routed to signal connectors, and the power & ground are distributed to each pad connector.

For the Main Distribution box, an aluminum enclosure was purchased, and the openings were cut using a scroll saw. The end-panels were made from light plywood in order to electrical isolate the metal case from the signal connectors. A side-effect of using the AC ground pin for 12V is that the snap-in panel-mount AC outlets connect 12V to the metal case.



Front view of a typical panel-mount outlet.



Front view of a typical panel-mount signal connector.

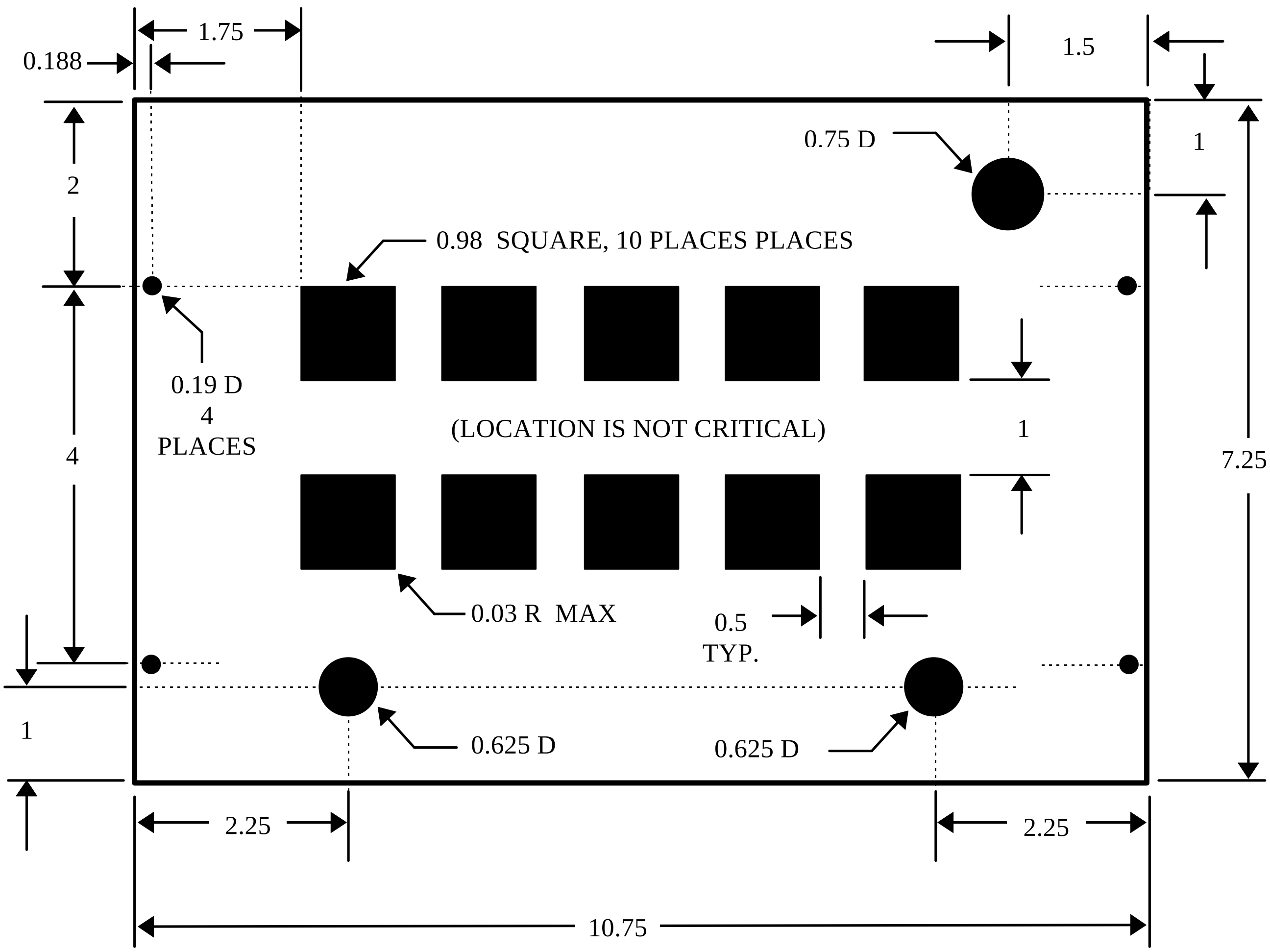
The 50-pin connector for the main cable is simply wired from pin 1 through 32 for the pads, and 49&50 are both ground. Up to 48 pads could be used with this cable for an even larger launch system.

The Expansion Boxes were donated by Rich Savory from surplus military equipment he found at an auction. The cases have a sealed cover, and mounting for a custom front panel. The panels were machined from the author's drawing by Ed Norris using stainless steel. The cases have enough room inside to hold the battery, and have a carrying handle. Two of these Expansion Boxes were built by the authors for the MARS system to serve primarily as left and right bank boxes for 10 high-impulse pads each. At smaller launches, one box has been used for as little as 3-5 high-impulse pads at 250 ft.

MARS LCS EXPANSION BOX FACE PLATE
John DeMar 5/27/97

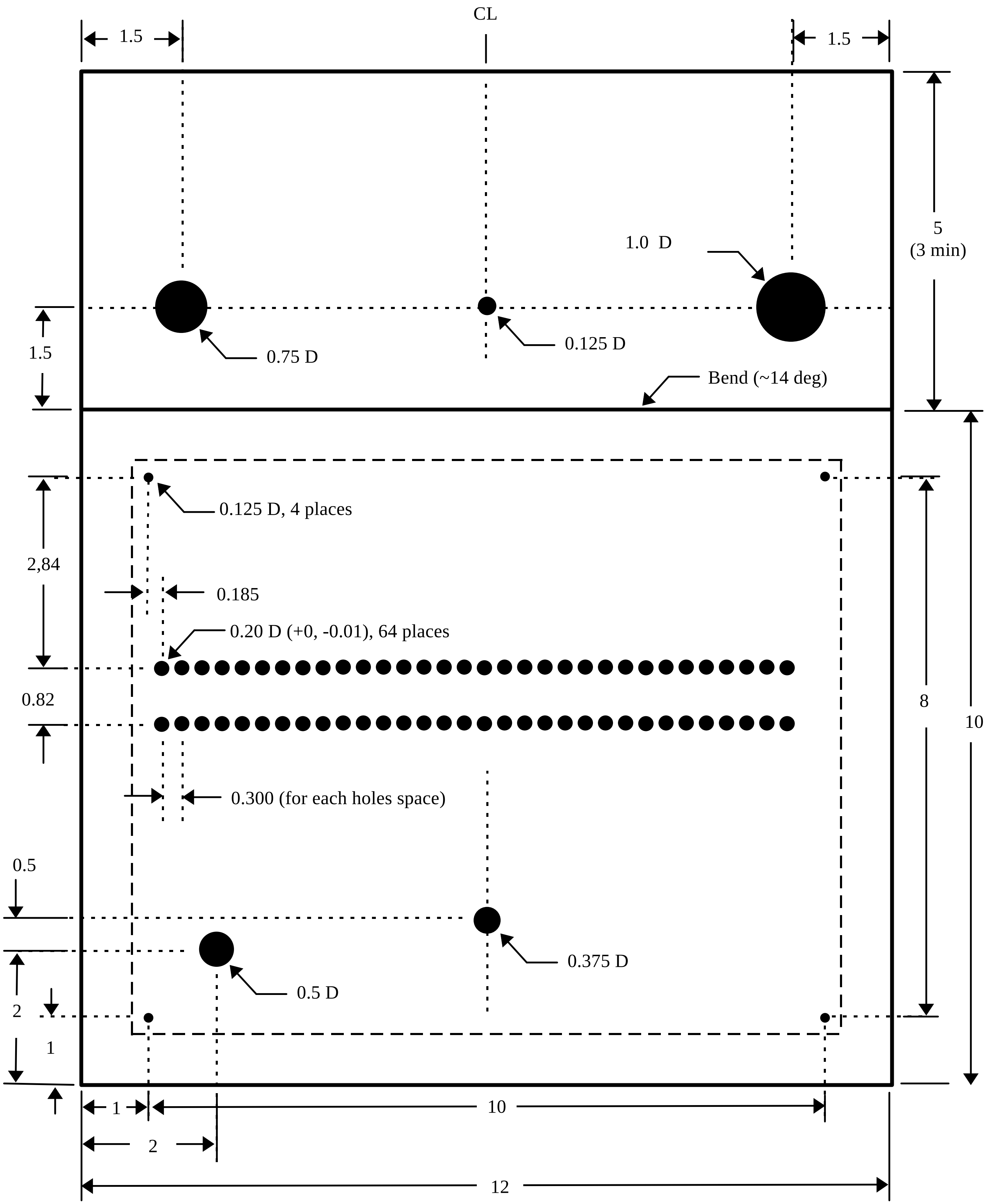
Dimensions in INCHES.
1/2 SCALE
(Sheet 1 of 1)

TWO REQUIRED



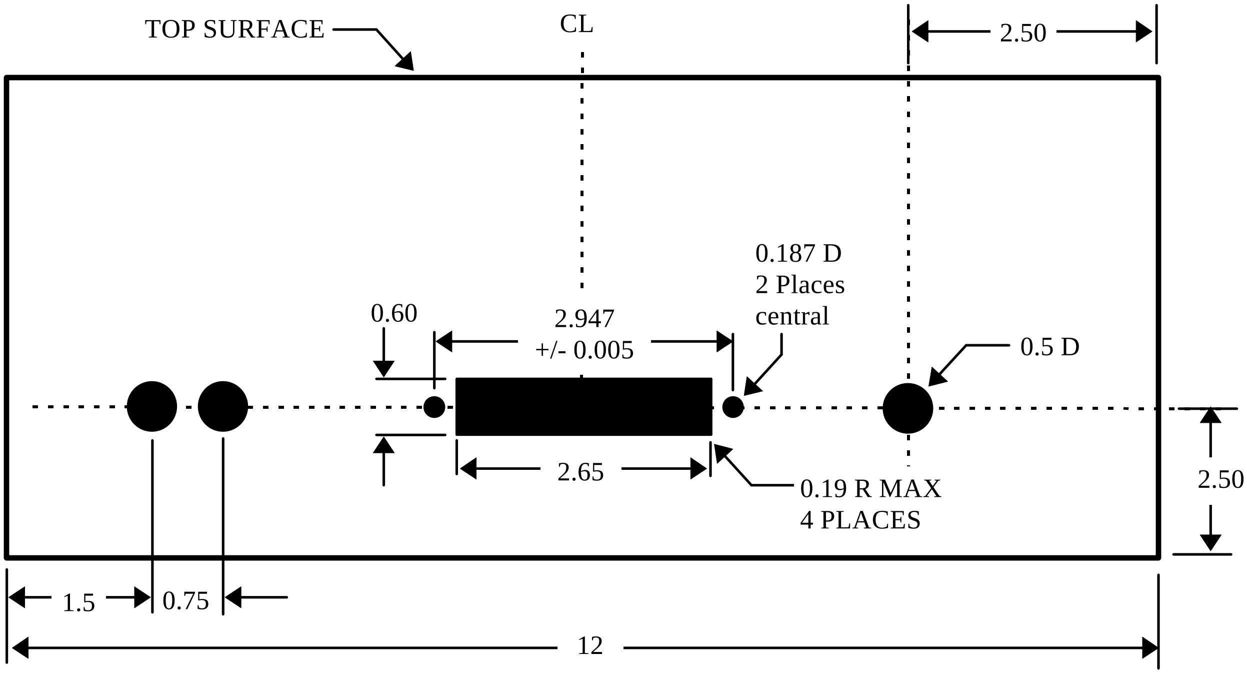
MARS LCS CONSOLE
John DeMar 5/27/97
315-451-6470

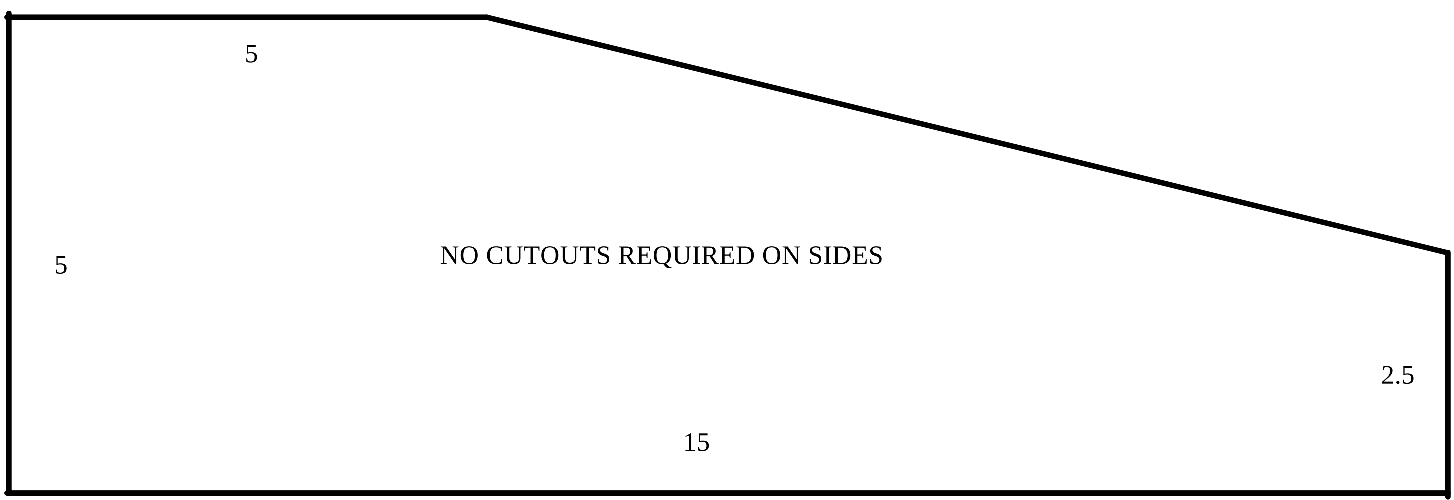
Dimensions in INCHES.
1/2 SCALE
Top View (Sheet 1 of 2)



MARS LCS CONSOLE
John DeMar 5/27/97

Dimensions in INCHES.
1/2 SCALE
Back & Side Views (Sheet 2 of 2)

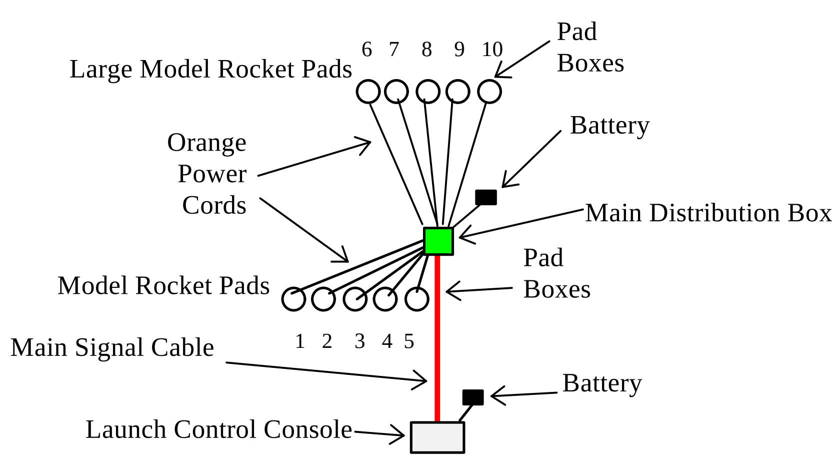




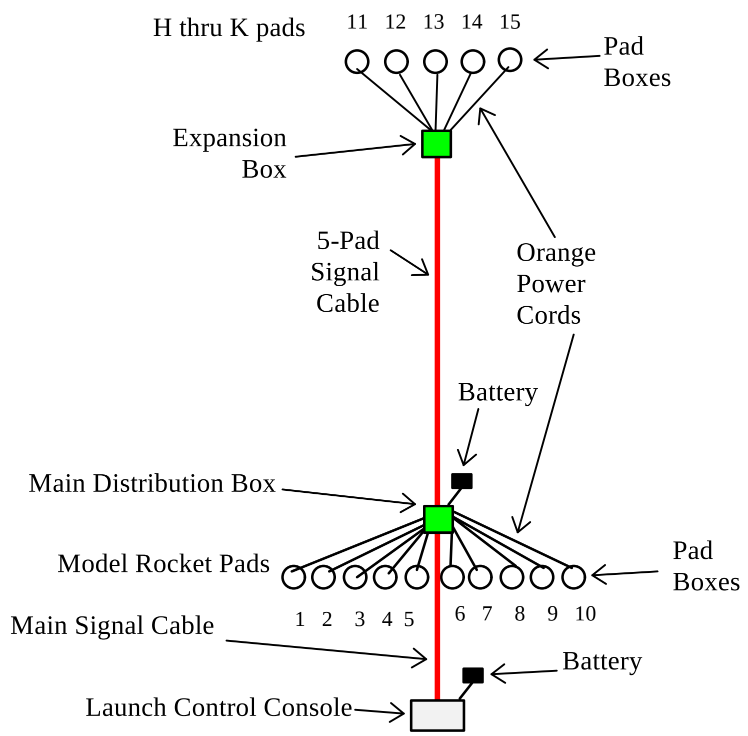
4.0 RANGE OPERATION

4.1 Layout Options

The MARS Launch System was designed to meet the needs of several types of club launches: model rocket meets, medium-sized waivered launches, and larger regional (or national) events. The following pages show some typical range setups that are possible using the same set of equipment.

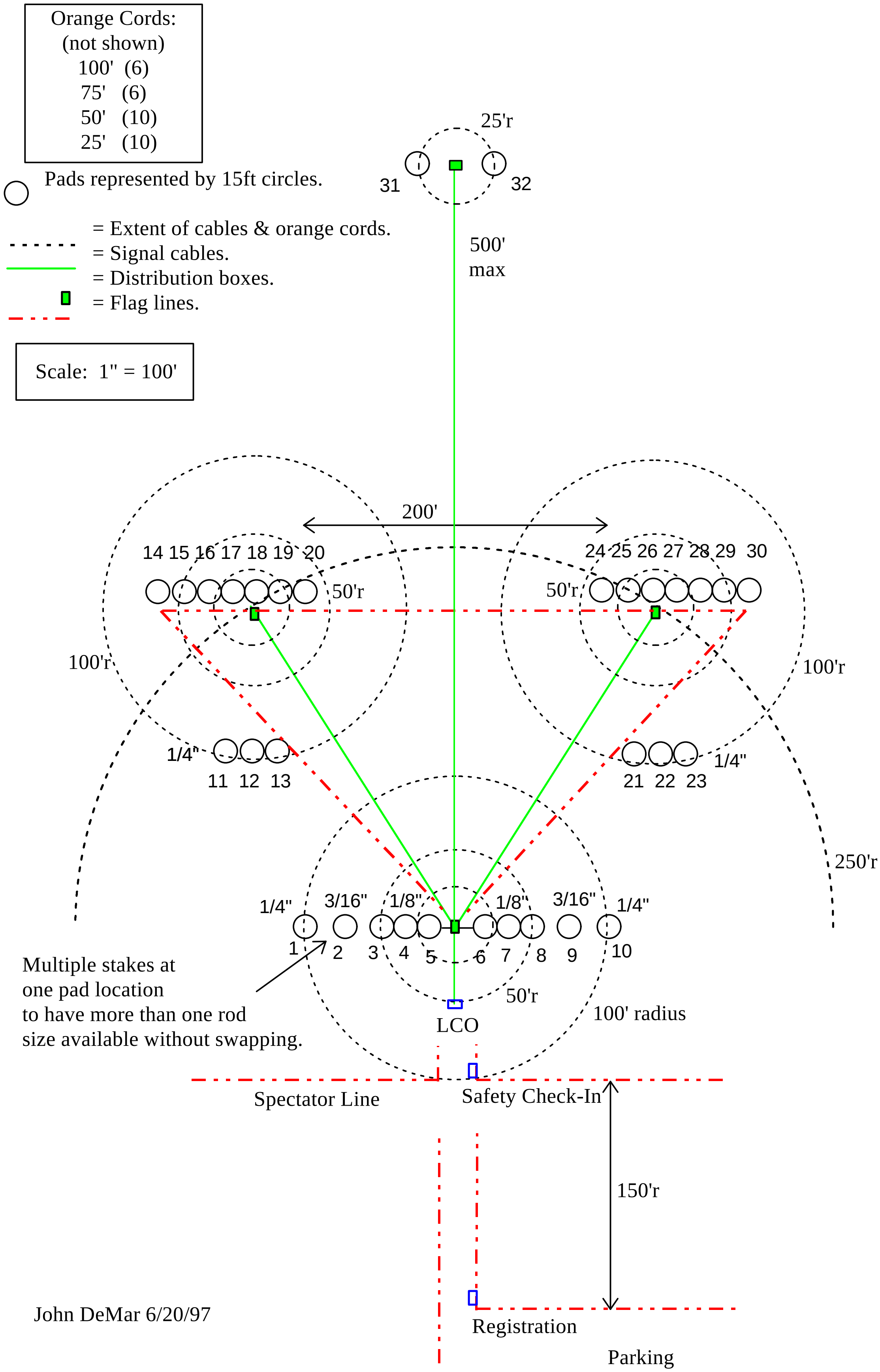


Small Layout for Local Club Launch



Medium Layout for a Waivered Launch

NATIONAL SPORT LAUNCH / NYPOWER '97
RANGE LAYOUT



John DeMar 6/20/97

4.2 Using the System

The Launch Control Console has a three-way switch with OFF being the middle position. The key is only removable when in the OFF position, ensuring that when the key is out, no one can use the system. In the TEST position, all continuity lights and the continuity can be checked, but the launch signal is disabled. All of the green LED's (top row) show the continuity status at each pad. If the pad box was left in the TEST position, the LED for that pad will be on continuously; if the pad box is in the ARMED position, then the LED will be blinking. By selecting a pad and pressing the CONTINUITY button, the tone from the selected pad will be heard. The higher the pitch of the tone, the better the igniter. If clips are dirty, or the igniter is poor, the tone will have a low buzzing sound. Copperheads, for instance, have a slightly lower tone than a solar igniter.

When the Launch key on Launch Control Console is in the ARMED position, the controller is now active and will launch the selected pad when the LAUNCH button is pressed. All other functions from the TEST mode (above) are useable while the key is in the ARMED position.

The Pad Box has a three-position toggle switch to select the mode. When in the OFF position, all power is disconnected from the relay and the continuity test circuit. This is the safe mode of the pad. When switched to the TEST position, the continuity circuit is active and will generate the continuity tone without having to hold down a button. This "hands-off" mode lets you hear how well your connecting the igniter without going over to the pad box to check. The tone will be on continuously in this mode, and the higher-pitched tone indicates a good igniter.

When switched to the ARMED position, the pad box is now ready to launch the rocket. The continuity tone will change to a pulsed (no-off) beeping to warn that the pad is now armed. The pad box must be switched to this mode before leaving the pad when ready to launch.

If the ARMED tone (on-off beeping) is heard while in the TEST position, this is a warning that the relay is already closed (failed contact, etc.). This special feature protects against this rare (but dangerous) situation. If the ARMED tone is heard while in the TEST mode, DO NOT switch to the ARMED mode, or the rocket will launch!

Setting up the range and connecting the system is very straight forward. The main cable is rolled out to 50 feet and connected to the Main Console on one end and the Main Distribution Box on the other end. Orange power cords of the required length are connected to the Main Distribution box and laid out to the closer pad position.

From the Main Distribution box, signal cables are unrolled from the cable reels to where the Expansion Boxes are required. Each cable plugs into the 5-pin round connector on the Main Distribution Box and the Expansion box. From there, the power cords are plugged in and laid out to the desired pad positions.

It is especially important to use cable reels for the 6-conductor (5-pad) signal cables. They will easily tangle if they are rolled up over an arm, requiring the patience of a saint to untangle at the next launch!

5.0 CONCLUSION

The 32-pad MARS Launch Control System was a major project developed primary by the members of the Phobos & Deimos Team. With the help of other MARS section members (especially Rich Savory, Ed Norris, and John Viggiano), this extensive set of equipment was built to last the club for many years, and will handle all levels of rocket launches.

Through careful planning and good engineering methods, the equipment was specified, designed, built, and tested to meet the cost constraints, and the requirements for a rugged, expandable system. The equipment was delivered in time for the club's spring launches, and was tested on the field in pre-planned steps during development. The final complete system was delivered in time for the National Sport launch, where over 600 flights were launched reliable from the new launch system.

This report includes all of the details needed to build a complete duplicate system, or to develop another version based on the innovations shown here.

APPENDIX A - SCHEMATIC DIAGRAMS

- **LAUNCH CONTROLLER SCHEMATIC**
- **PAD CONTROLLER SCHEMATIC**

APPENDIX B - PARTS LISTS

- **LAUNCH CONTROLLER PARTS LIST**
- **PAD CONTROLLER PARTS LIST**
- **DISTRIBUTION BOX PARTS LIST**
- **EXPANSION BOX PARTS LIST**
- **TOTAL COSTS ~= $500** for the complete system + batteries + orange cords.

APPENDIX C - ADDRESSES OF SUPPLIERS

Circuit Specialists P.O. Box 3047 Scottsdale, Arizona 85271-3047 800-528-1417 602-464-5824 fax	Die-cast aluminum cases. Toggle switches.
Digi-Key Corporation 701 Brooks Ave. South Thief River Falls, MN 56701-0677 1-800-DIGIKEY	50-pin centronics connector Rotary encoder
MECI 340 E. First St. Dayton, OH 45402 Phone: 1-800-344-4465 Fax:1-800-344-6324	Cable, and batteries.
Hosfelt Electronics, Inc. 800-524-6464 800-524-5414 fax	Bulk of electronic components. Relays, and breakers.