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16th Annual AIAA Digital Avionics Systems Conference

A LOW COST AVIONICS SYSTEM SUPPORT APPROACH FOR LOW COST LAUNCH VEHICLES*✞

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ABSTRACT

Reflections To The Future, highlights the need for low cost avionics systems, suitable for use on simple sounding rockets, up through orbital insertion. Microcosm, has designed and built such a low cost Avionics Suite in support of the NASA-Marshall SR-S sounding rocket The SR-S concept is based on earlier Microcosm work in recognition that launch vehicle development costs plus operational costs far exceed unit build costs. Design of a Digital Avionics System, to truly minimize cost, required that all development and operational aspects be part of the design, particularly *Safety, Reliability and Cost*. Modularity techniques were adopted which avoided expensive and complicated design, development and integration. Several interesting approaches are described in this paper: 1) a safe and simple battery power system, 2) safe, reliable and low cost cabling, wiring and umbilical system, 3) Programmable Built-In-Test/ telemetry system, 4) innovative construction techniques and materials, and 5) a system designed by choosing components that together, provide the lowest life cycle cost with adequate performance. The Generic Navigation and Control system, implementation using modularity and scaleability principles, promise future reusability at system, equipment, module and component levels.

INTRODUCTION

The SR-S is a NASA Sounding Rocket Technology Demonstration program, based upon Microcosm Scorpius Launch Vehicle technology, implementing cost reduction measures defined by John London[i].

THE SCORPIUS STORY

The Scorpius avionics story is about aspects of both technology and humanity. Technology aspects are about design philosophy, strategy and implementation tactics. Human aspects are largely about mindset, or the breaking of mindset. For successful development of dramatically lower cost launch vehicles, top experts were brought together as a team at Microcosm[ii].

However, experts bring successful experience to bear, which also brings the problem of mindset. The way to break mindset is the "*clean sheet approach*." Let experts begin anew, with a clean sheet in each discipline. However, the clean sheet approach leads to "*reinventing the wheel*" problems. Thus the Scorpius story is about balancing technology design philosophy, strategy and implementation tactics with a clean sheet approach. Mindset is broken by clean sheet design for functional necessity,

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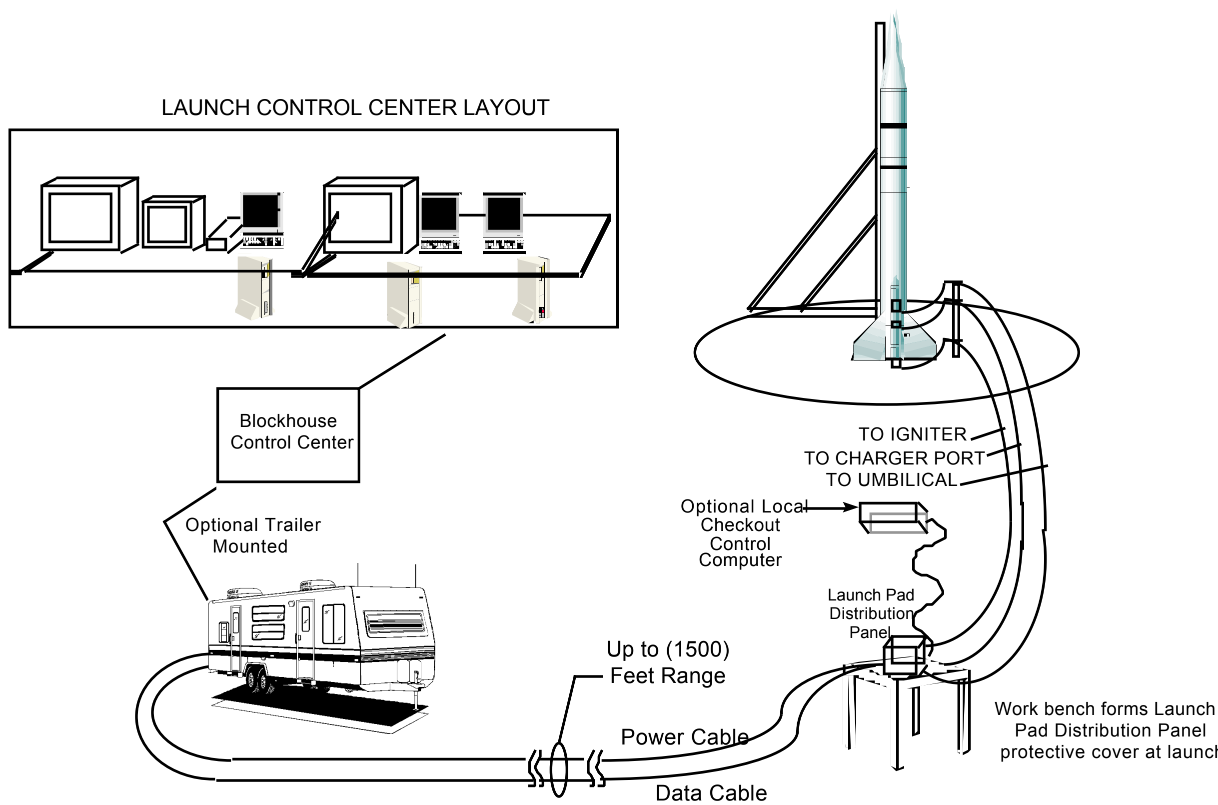
and reinventing the wheel is avoided by philosophy, strategy and implementation tactics of existing technology and reuse.



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SR-S Overall System Perspective

THE SCORPIUS CONCEPT

The Scorpius family of expendable launch vehicles has the objective of reducing near term launch costs by a factor of 10.

The SR-S, a NASA sounding rocket, is interesting in that it is a scaling down technology which was originally conceived to be scaled up. The Scorpius concept has the following characteristics:

SCORPIUS PHILOSOPHY

The mindset that launch vehicles must be as light (costly) as possible, to deliver the greatest payload, must be broken. The correct philosophy is that launch vehicles must be as low in cost as possible, to deliver the greatest payload. This is true, since launch vehicle

- Dramatically *decrease* the cost of access to space
- *Break existing mindset* on what to do and how to do it
- *Lower development costs* by one hundred fold
- *Lower recurring costs* by ten fold
- Apply LV cost savings to *decreasing upper stage/payload weight*.

cost saving can be applied to making the payload as light as possible! Thus the Scorpius philosophy is:

- Upper stage weight reduction is as much as 1000 times more important than launch vehicle weight reduction

- Development cost reduction is as much as 100 times more important than recurring cost reduction
- Recurring cost reduction of as much as 10 fold occurs by designing for functional necessity, modularity and scaleability.

SR-S Avionics Modules With Mounting Hardware

SCORPIUS STRATEGY

The “clean sheet“ design for functional necessity strategy is stated as:

- Reduce all avionics costs by minimizing extraneous requirements
- Reduce avionics *development costs* by reuse of existing technology
- Reduce avionics *recurring costs* by reuse of design within a Scorpius LV
- Reduce avionics development *and* recurring costs by reuse of design across Scorpius LVs
- Reduce avionics costs by *moving complexity into software*

SR-S Avionic Components and Isolated Mounting Plate

SCORPIUS TACTICS

The clean sheet design for functional necessity is implemented tactically by use and reuse of existing technology:

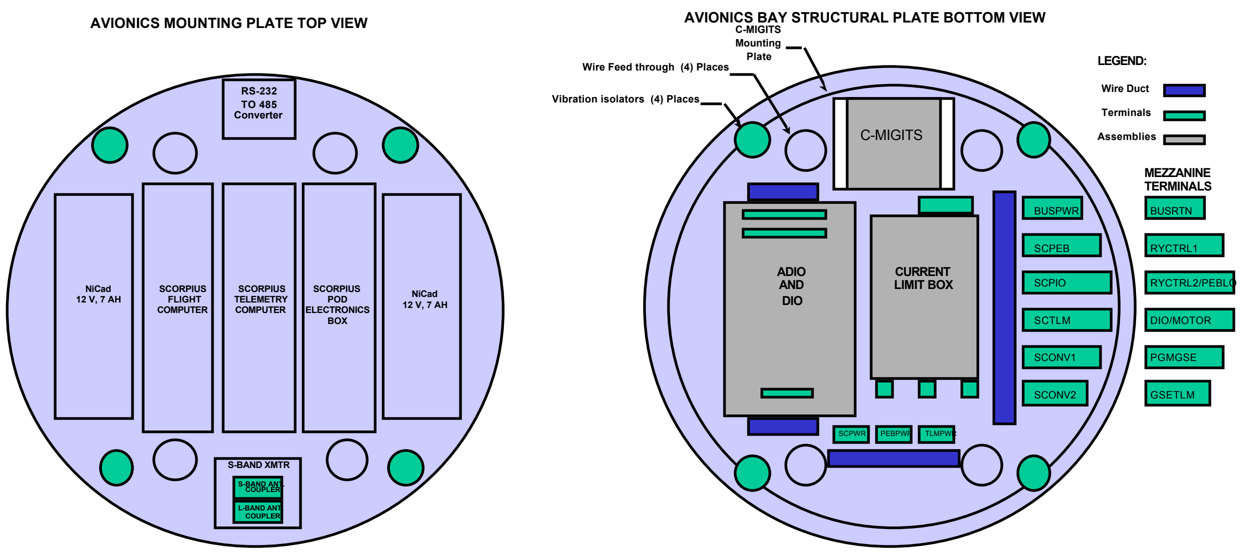
- Select high performance per dollar *Parts, Materials, Processes and Components* (PMPC) throughout
- Minimize PMPC types used throughout
- Minimize PMPC quantities used throughout
- Use selected PMPC across LV programs to rapidly accumulate experience data
- Design, Build and Test avionics (Rapid Prototype) prior to design freeze
- Develop avionics and matching test sets at all levels
- Design for Built-In-Test (BIT) within avionics, which results in a marriage of BIT and Telemetry
- Design for Ground Support Equipment (GSE) to double as Integrated Test Equipment
- Make widespread use of the high power per dollar of Personal Computers (PCs)
- Use software simulation models as an effective part of testing

SR-S Avionic Mounting Plates with Components

SCORPIUS IMPLEMENTATION

Implementation integrate the Scorpius concept with the stated Philosophy, Strategy, Tactics and human issues (breaking mindset):

- Iteration of the system design consistent with the stated Philosophy, Strategy and Tactics
- In practice, this frequently leads to selection of Commercial-Off-The-Shelf (COTS) PMPC, wherever practical
- COTS usage requires a protected avionics bay approach
  - The Avionics Bay is an all aluminum “cylindrical can” for thermal and electrostatic protection
  - Avionics are primarily mounted onto a three axis vibration isolation disk within the Avionics Bay
  - Printed Wiring Boards Assemblies are mounted in aluminum boxes filled with packing foam
  - Avionics boxes are mounted to the isolation disk using energy absorbing pad and grommet material
  - Avionics boxes are electrically interconnected at distribution panels, using industrial terminal blocks
  - Box connectors and the umbilical use a standard set of pre-manufactured cables with connectors at one end, designed for use across all Scorpius vehicles
  - Cables are wired in place using industrial terminal blocks

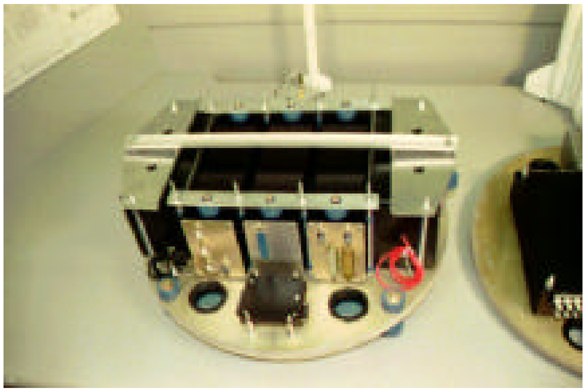


SR-S Component Layout, Upper and Lower Plates

GUIDANCE, NAVIGATION AND CONTROL

An integrated Guidance, Navigation And Control (GN&C) system uses a COTS unit called the C-MIGITS II. GN&C characteristics of interest are:

- C-MIGITS II integrates Global Positioning System (GPS), Accelerometers and Rate Gyros with a Digital Signal Processor running Kalman filter algorithms
- C-MIGITS II filtered output provides the best of both GPS accuracy and Inertial Navigation System (INS) response, since all errors wash out with time

SR-S Upper and Lower Mounting Plates Prior To Integration

SCORPIUS COMPUTER CONTROL

Control is provided by the Scorpius Computer, which is largely COTS technology, based on an earlier 80x86 flight control project:

- All Input/Output (I/O) is via Opto-Isolated serial bus
- Single Fault Memory detection/correction is employed
- Flash EPROM provides reprogramming and flight parameter update via GSE up until launch
- RS-485 Serial buses link the computer with:
  - C-MIGITS-II
  - GSE Data
  - Telemetry Computer
  - Pod Electronics Box

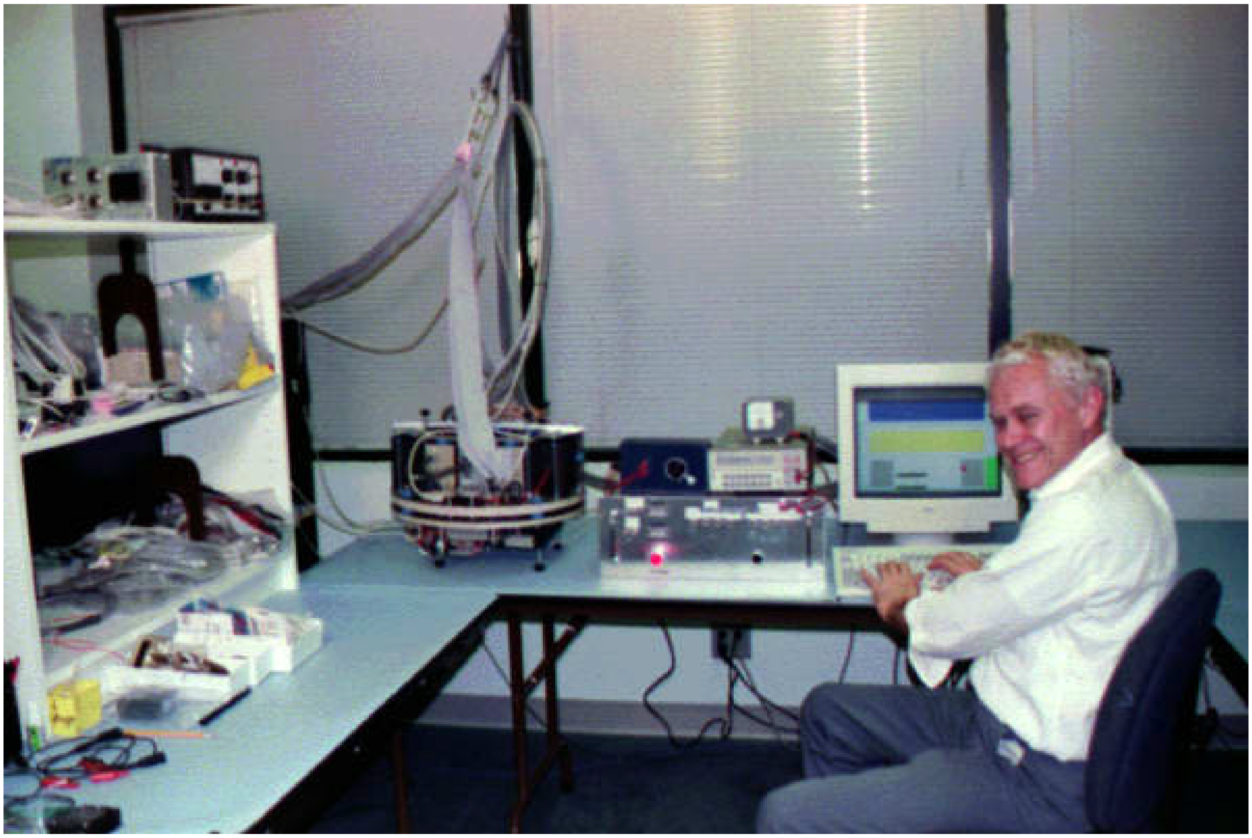
SCORPIUS POD ELECTRONICS

The Scorpius Propulsion Pods are controlled by Pod Electronics Box (PEB) mounted solid state PhotoRelays, Opto-Isolating all propulsion valve circuits. The PEB also provides sensor data acquisition for relay back to the Scorpius Computer

SCORPIUS TELEMETRY COMPUTER

The Scorpius Telemetry Computer provides for programmable, software controlled telemetry data acquisition and formatting. The Telemetry Computer is based on several COTS, PC/104 format PWBAs:

- 486 Single Board Computer with Flash EPROM programmability
- Remote data acquisition via a Quad RS-485 Communications Board
- Local data acquisition via a 16 Channel Data acquisition Board
- Power Supply Board
- A custom Telemetry Board for IRIG Standard Type I formatted output
  - PC/104 board format construction
  - Low software overhead via word wide data bus transfer and large First-In-First-Out (FIFO)
  - Remote data acquisition via COTS RS-485 controlled Analog-To-Digital Boards

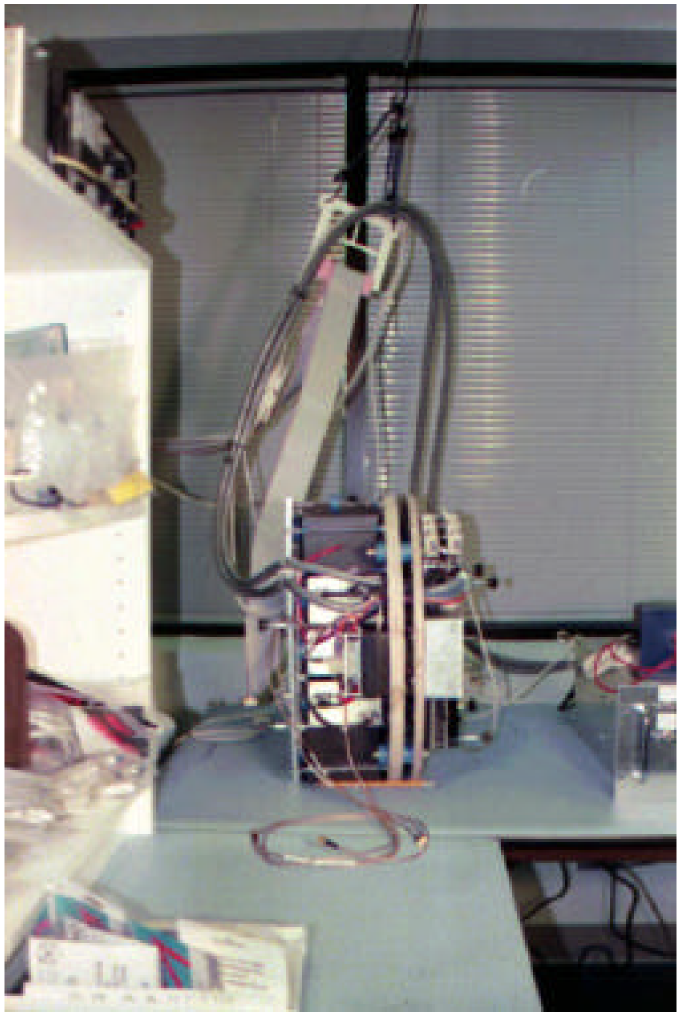


SR-S Avionics Integrated and Fully Functional

VEHICLE POWER

Reliable, low cost vehicle power is provided by hermetically sealed 24 Volt NiCad batteries. Interesting features are:

- Battery charge and discharge is remotely controlled from the Launch Control Center
- State-Of-Charge is monitored by a dedicated State-Of-Charge Micro-controller, accessible via the GSE RS-485 bus (not implemented on first flight vehicles due to budget limits)
- Remote status and power ON/OFF is provide for during test and pre-launch via GSE RS-485 controlled DIO
- Automatic Electronic Current Limiting protection of all 24 V powered circuits from inadvertent short circuits, from system integration up through pre-launch (which eliminates most induced damage failures)
- Current Limit Groups:
  - Group 1 – C-MIGITS, Scorpius Computer and Scorpius Pod Electronics
  - Group 2 –Telemetry Computer
  - Group 3 –Telemetry RF Transmitter
  - Group 4 through 7 – Propulsion
  - Group 8 – Spare



SR-S Avionics Undergoing Integration Testing

CONSTRUCTION

Material was selected for low total system cost and function. COTS aluminum boxes, and aluminum sheet metal are used predominately:

- Avionics Bay cylindrical section of aluminum
- Aluminum-composite structural avionics bay disks
- Three axis vibration isolation disk for avionics mounting
- Vibration isolated pad and grommet mounting techniques
- Threaded shaft (stud) type mounting hardware with Locktite/Nylon Locking Nuts used throughout
- Distribution panel mounted industrial terminal block interconnect
- Industrial plastic cable ducting used for wire and cable routing
- Pre manufactured cables with high quality connector-crimp pin construction used for cables
- MIL Spec AWG #20 wire used throughout Avionics Bay
- MIL Spec, high temperature, high strength annealed copper wire used in shielded cables, external to Avionics Bay

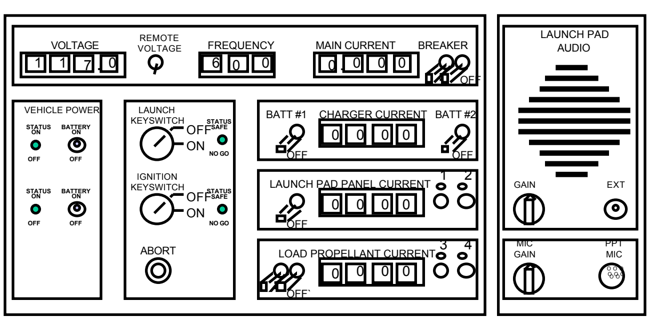
SR-S Structural Design, With Vibration Test Antenna Mount (Top), and Vibration Table Adapter (Bottom)

LAUNCH VEHICLE GROUND SUPPORT

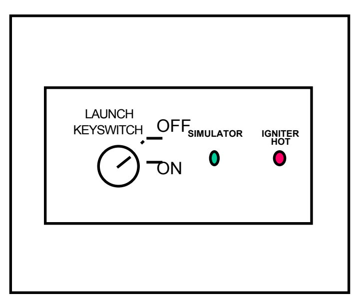
An integrated, scaleable, vehicle and Ground Support Equipment (GSE) design approach is used:

- Umbilical wire reduction via GSE remote data acquisition RS-485 controlled Digital I/O (DIO) Board
- Launch Pad to Launch Control Center wire reduction via GSE remote data acquisition RS-485 controlled Analog-To-Digital (ADIO) and Digital I/O (DIO) Boards

POWER CONTROL PANEL FRONT VIEW



IGNITER INTERLOCK PANEL FRONT VIEW



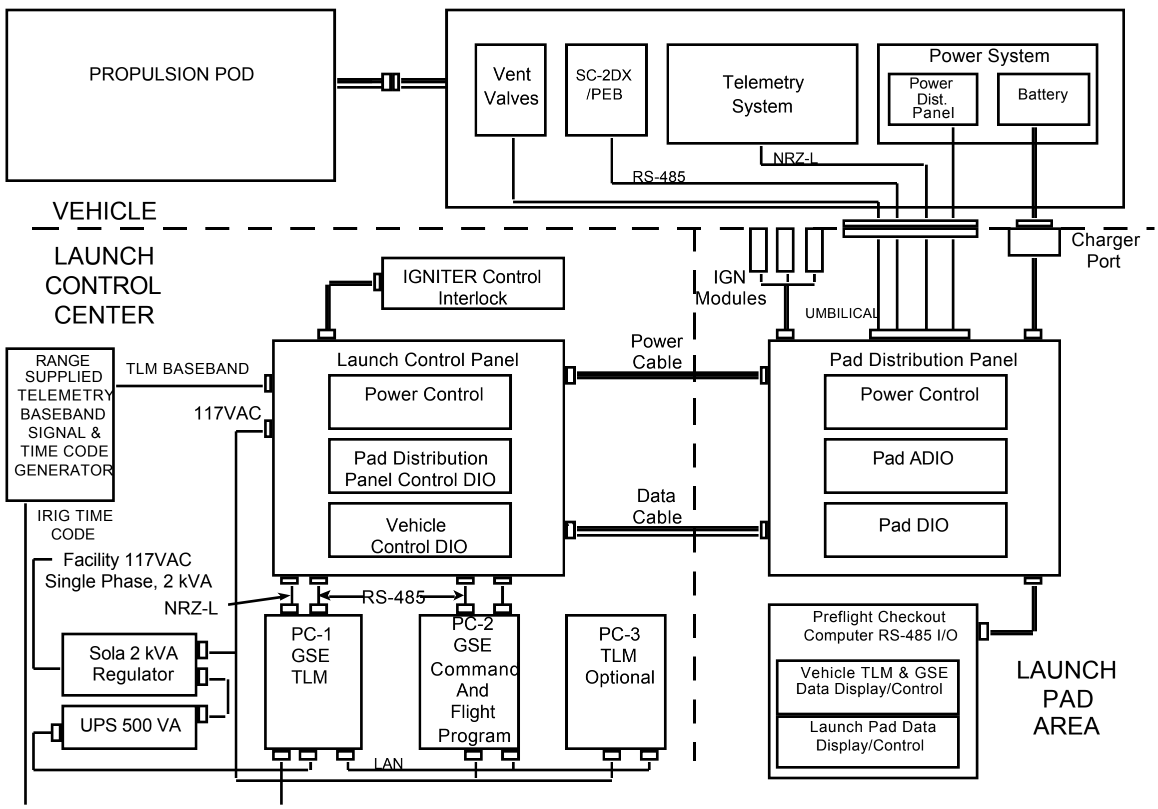
Control Center Hardware Panels

GROUND SUPPORT EQUIPMENT

PC controlled RS-485 Bus interconnects launch control center, Launch Pad and the vehicle. Keynotes of the GSE design approach are:

- Launch Control Center Equipment
- Launch Control Panel
- Launch Control Igniter Interlock Panel (Range Safety)
  - Launch Control Personal Computers for:
    - GSE vehicle monitoring, pre-launch and launch control
    - Telemetry data capture and recording
    - Varied Telemetry data displays
- Pad Video Camera/Monitors
- Launch Control Regulated Power
- 2kVA power regulator
- 400VA Uninterruptible computer power

GSE LAUNCH PAD OPERATIONS SYSTEM DIAGRAM



CONTROL-TO-LAUNCH PAD CABLING

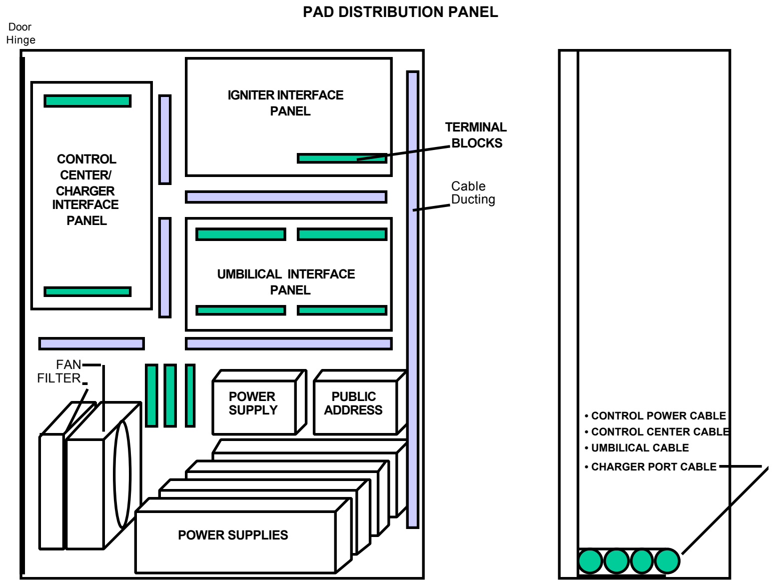
Scorpius GSE design provides for 1000 feet of cable from Launch Control Center to Launch Pad Distribution Panel

- Launch Control-Center cabling can be extended to over 5000 feet with scaling of power cable conductors and the use of data Modems for RS-485 and Telemetry data links
- Launch Pad Distribution Panel contains:
  - Switchmode Regulated DC power supplies
  - Launch Pad data acquisition and control boards
  - Igniter power and control circuits
  - Umbilical interface
  - Battery Chargers and Battery Port Interface
  - Launch Control Center-To-Launch Pad Communication
- Telephone
- Intercom/Public Address
- Pad Local Monitor/Checkout panel I/O
- Launch Pad To LV Cabling

- Scorpius GSE design provides for 100 feet of cable from Launch Pad Distribution Panel to LV

- Umbilical cable is COTS outdoor multi-conductor data pair cabling
- Battery Charger Port cabling is COTS outdoor multi-conductor power cabling

Igniter power and control cabling is COTS outdoor multi-conductor data pair cabling



Launch Pad Distribution Panel Equipment Arrangement

SYSTEM TESTING

Highest performance/dollar avionic testing occurs at the lowest level for each Part, Material, Process and Component (PMPC). Similarly, testing is relatively complete for each function at each system level. Lower level tests are redundant and costly. This results in testing, with decisions made along the following lines:

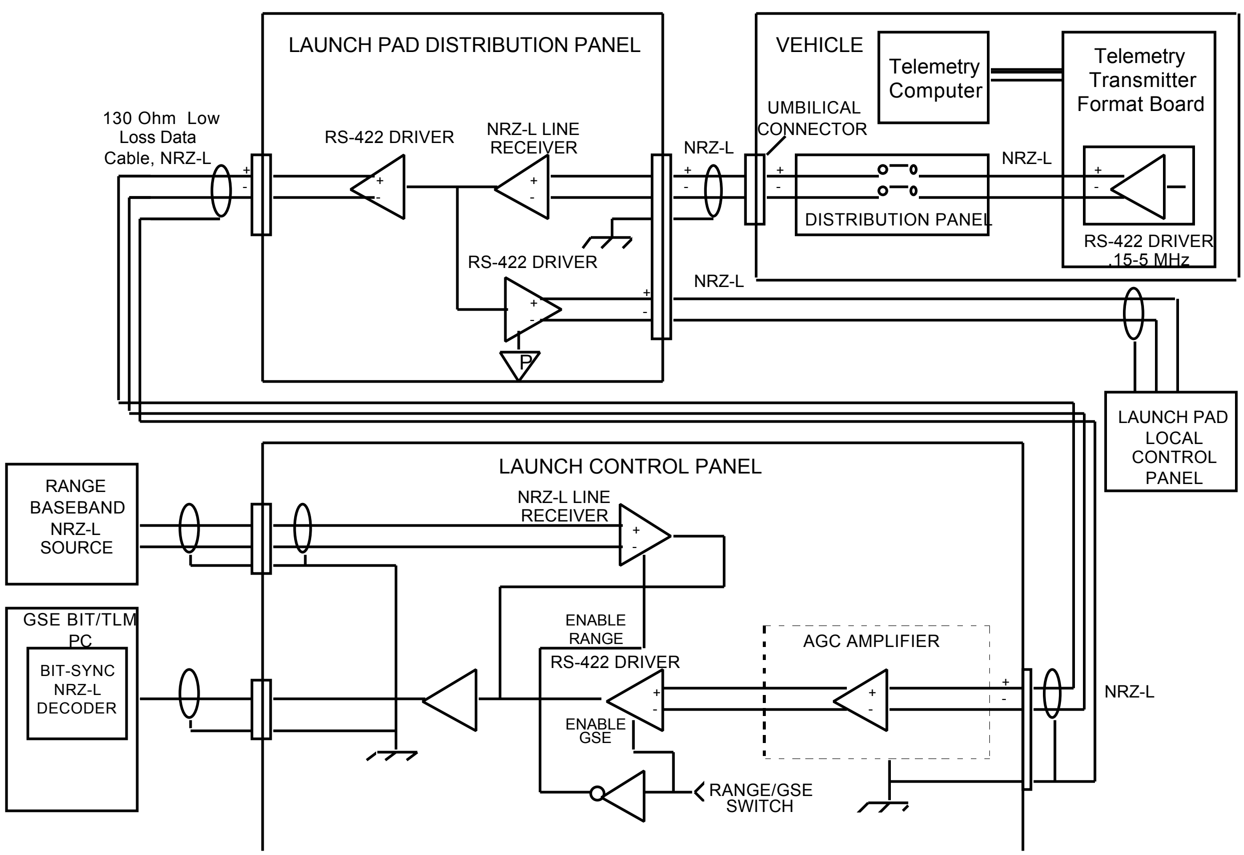
- Use real Launch Control-Center and Launch Pad equipment as part of Avionics Lab Test setup
- Use Combination of software model simulation and real hardware testing:
- All software model simulation
- GPS simulator with software model simulation
- Three-Axis table simulator with software model simulation
- Real aircraft flights with actuator simulation
- Combinations of the above

SYSTEM TESTING SUMMARY

TESTING ARENAS				
Hardware-In-Loop TESTING	**GPS**	**RATE GYROS**	**ACCELEROMETERS**	**CONTROL LOOP**

Static Bench Test	Software Simulation			
Three-Axis C-MIGITS Mounting	Software Simulation		Hardware Test	
GPS RF Simulator	Hardware Test	Software Simulation		Hardware Test
Three-Axis C-MIGITS & GPS RF Simulator	Hardware Test	Software Simulation	Hardware Test	Hardware Test
Aircraft Flight	Hardware Test			Software Simulation

BIT/TLM DATA COMMUNICATION DIAGRAM



SUMMARY

SR-S Avionics Bay environmental testing was conducted successfully at NASA Marshall facilities in October 1997. Microcosm, Inc., is now looking forward to a first launch, possibly in January 1998. With a successful launch, the NASA SR-S Sounding Rocket Technology Demonstration program will prove out many of the low cost concepts defined by John London.

Aspects of technology and humanity in terms of design philosophy, strategy and implementation tactics, the breaking of mindset and the "*clean sheet approach*," without "*reinventing the wheel,*" will all become more interesting. Thus the Scorpius story is about balancing technology design philosophy, strategy and tactics with a clean sheet approach, with existing technology and reuse.

We can already say that:

- SR-S avionics development (non-recurring) costs have been a real challenge, both in terms as a percentage of the low SR-S total recurring costs and absolute costs
- SR-S avionics non-recurring costs have been a similar challenge
- SR-S avionics technology is truly a subset of the Scorpius family

On all fronts we have meet the challenge.

CONCLUSION

There are several conclusions at this point:

- The Scorpius concept, implemented in the NASA SR-S, has already resulted in dramatically lower development costs for sounding rocket avionics
- The Scorpius philosophy, strategy and tactics applied to the NASA SR-S, have resulted in dramatically lower avionics recurring costs
- The Scorpius modularity and scaleability principles have been successfully applied to the NASA SR-S, in scaling down launch vehicle avionics.

References:

[i] 1. London, J., LEO on the Cheap, Air University Press, 1994, pp102-111

[ii] 2. J. Wertz, et al, Status of the *Scorpius* Low Cost Launch Services Program, paper SSC97-XI-5, presented at the 1997 AIAA/USU Conference on Small Satellites,