3.6 Ground Support

Ground Support provides several functions in support of the overall SRP4 mission:

- Communication with and activation/deactivation of the payload prior to launch.
- Provision of ground-based GPS tracking and RF power data during the flight
- Archival of all flight, science, GPS, and RF power data during the flight
- Display of the collected data in real-time during the flight
- Display of the archived data after the flight
- Processing of the archived data into data products

In order to accomplish these tasks the ground support system has several components which are described in this section.

3.6.1 Umbilical Box and Cable

Requirements

- Activate and deactivate of onboard systems, including separate activation of the EED board.
- Report EED board activation.
- Allow data flow to and from the flight computer.
- Monitor onboard power system.
- Charge onboard batteries.

Description

The umbilical box will allow for the remote activation/deactivation of the power board, charging of the batteries, monitoring of the battery charge status, and two-way communication with the flight computer. A drawing of the umbilical box layout and its connections can be seen in Figure 3.6.1.1.

The umbilical cable terminates with a 37 pin cannon type plug which will be converted into a 15 pin High Density (HD) D type connector (female) which will connect to a male 15 pin HD D type connector on the umbilical box. The 15-pin connector will pass all flight computer information directly to a 9 pin D connector, which will be connected to one of the telemetry computers. A monostable 555 timer will be attached in parallel to the data coming in from the flight computer to act as data transmission light. The umbilical box will use two alkaline 9V batteries for power in which case no external power will be required (if the box is used for a short period of time). The payload batteries will be charged through a battery charger (being designed elsewhere) attached through the umbilical box. A detailed list of the functions of the pins for each D connector can be found in Tables 3.6.1.1-3.6.1.3.

Design

Data Transmission LED

The circuit can be seen in Figure 3.6.1.4. It is a simple 555 timer set up for a monostable pulse. The RS-422 from the flight computer transmits a binary stream of data. The MAX2471 acts as a differential buffer to buffer the signal. The 555 timer is connected so that when a pulse is detected a ¼ second pulse is delivered to the output. The pulse at the output lights up a green LED. Before the pulse activates the LED it passes through a resistor to prevent damage to the LED. When the pulse is completed the timer looks for another one. If the output from the RS-422 is stuck at ground or 5 volts there will be no pulse to activate the 555 timer. The 555 has minimal input impedance, but to ensure that the serial line is not loaded a buffer (a MAX2471 differential buffer) will be placed between the input line and the trigger of the 555.

"Main Power ON" EED Board LEDs

The circuit can be seen in Figure 3.6.1.5. When the power system onboard the rocket is activated the power board will begin to generate different voltages (+5V, +/-15V, etc.) for the different components onboard. The umbilical will be attached to one of the +5V outputs. When the power board is activated the +5V will activate the red LED in Figure 3.6.1.5. For the same reason as in part A, a buffer will be placed on the input between the 5V in and the resistor seen in Figure 3.6.1.5. The circuit in Figure 3.6.1.2 is specifically for the “Main Power On” LED but the same circuit will be used for the “EED Board On” LED with the input from pin 10 of the 15 pin HD D type connector.

Internal Battery Switch, Main Power Switch, and EED switch

The circuits can be seen in Figures 3.6.1.2 and 3.6.1.3. When the internal battery switch is activated the power from the 9V batteries is made available to the umbilical box or the power from an externally connected DC power supply. This is required for the main power switch to be activated or the EED board switch to be activated. Note that these switches must be held in the on or off positions for 4 seconds then released for the circuit to be activated. Upon release the switch will return to a neutral position. The umbilical power switch is a three-way switch with the right set to toggle the internal supply, the left set to toggle the external supply, and the center toggle set to ‘Off’. The main power switch is also a three-way toggle, in this case the right toggle is set to ‘On’ the left toggle is set to ‘Off’ and the center toggle is set to neutral. This is also how the EED board power switch works. Also, if there is a failure of the 9V batteries then an external dc supply can be attached to the +9V banana jack and the rockets power can still be activated. The ‘Charge Internal Batteries’ switch connects the banana plugs to the internal batteries, so the batteries can be charged by an external DC supply.

Voltmeter

The voltmeter attaches in parallel to the payload battery by way of the Sensor connection. The voltmeter will monitor the overall voltage of the battery pack to ensure that the maximum of 36V is not exceeded, which would damage the batteries. The voltmeter selected is a generic analogue multi-meter from Radio Shack. It has a high enough impedance that the 10 kΩ resistor in the rocket will have no effect.

Umbilical Box Internal Power

The circuit is given in Figure 3.6.1.3. The internal power for the umbilical consists of four rechargeable 9V batteries. Two will be connected in parallel to each other so they deliver +9V and the other two are connected in parallel so they deliver –9V. The blue and green banana jacks will provide the ability to connect a dc power supply if the batteries drain while umbilical box power is still needed (see section C). Both supplies will provide power to the rails of the buffers while the positive supply will provide power to the main power switch as well as the other circuitry in the box.

Payload Battery Power

The payload battery bank will be charged with a battery charger connected over the umbilical. The battery charger will connect to the umbilical by way of the payload battery port on the umbilical box (the Molex connector). In addition to the power connection on the

Molex connector, there will also be pins connected to the batteries by way of the umbilical for the battery charger to monitor the charge status.

Pin Connections

The pin connections for each of the D type connectors are listed in Tables 3.6.1.1-3.6.1.3.

Sensor

The Sensor connection, shown in Figure 3.6.1.1, is used by the voltmeter to measure the rocket battery bank. There is a diode on the power line that blocks any reading from the voltmeter. Because of this a separate line is needed to monitor the battery voltage. This line will also be routed to the charger connector so the battery charger can use it for accurate charging.

Ground

Multiple pins in the D type connectors have been allotted for ground lines. This is for multiple devices that might need ground, but all the grounds will be tied together in the umbilical box.

Cannon to D type Adapter

The connections can be seen in Figure 3.6.1.6. The umbilical cable between the launch pad and the blockhouse is terminated with two female Cannon type connectors. This adapter extends the length of the umbilical to reach the rocket/umbilical box and allows transitions to the female 15 pin HD D-type connector. The exterior view in Figure 3.6.1.6 shows how the wires will connect from the D-type connector to the Cannon plug. The interior view shows how each line from the 15-pin connector is attached to three lines in the umbilical (through the Cannon plug). This is done to reduce the total resistance seen by the signal traveling through the umbilical. Each line in the umbilical has a line resistance of approximately 8Ω. Connecting three lines in parallel will drop that resistance to approximately 2.7Ω. Unfortunately, there are not enough connections in the Cannon plug for three lines to be attached for one signal. This results in using two lines in parallel for each signal except for the power in line and all five of the data transmission lines.

3.6.2 Ground Support Blockhouse Computing Resources

Requirements

- Accept telemetry data from flight computer via umbilical cable.
- Display results of telemetry data received.

Hardware

A computer capable of receiving data from the onboard flight computer will be situated in the blockhouse. The serial data stream from the flight computer will be received via the umbilical cable. The data will consist of both the flight computer health check data on system reset, and the flight data packets collected by the flight computer prior to launch. Any Pentium II or later computer with an RS422 interface and running either Windows NT or Windows 2000, will be suitable for this task.

Software

The blockhouse computer will run software similar to the telemetry station ground support computer, but the data input rate will be lower at the blockhouse. This is because ground-based GPS or RF power data will not be processed, and there are possible umbilical cable data rate limitations.

3.6.3 Ground Support Blockhouse Computing Resources

Requirements

- Accept telemetry data from receiver station.
- Validate data packets received from receiver station.
- Archive received data.
- Display data from either archived or real-time sources.
- Accept, archive, and display ground-based GPS data.
- Accept, archive, and display RF power data.
- Process data into data products.
- Save data products in a format that can be distributed to data consumers.

Hardware

A computer capable of receiving, archiving, and displaying the serial data streams of data packets from the communications group, the GPS data from the ground GPS system, and the RF power data is required. This machine must also have the available hard disk storage needed to store all data received over the duration of the flight. Given that the expected data rate from the vehicle via the communications group is ~50,000 bps, and since ASCII storage format will be used, the flight data storage requirements are approximately 90Mbytes per hour. Minimum requirements for the telemetry station computer are:

- A 20+ Gigabyte hard drive for data archiving.
- 128MB system RAM
- A Windows NT or Windows 2000 operating system
- A large capacity removable media drive, such as a CD/RW device.
- An RS232 interface, and either a RS422 interface card capable of receiving two separate data streams, or two RS422 interface cards.
- Intel Processor running at the highest available clock speed.

In an effort to reduce the risk or effect of a loss of power during the flight, an Uninterruptible Power Supply (UPS) system should be attached to the telemetry computer. This will allow for the continued operation of the telemetry computer during a short power outage. The use of a generator to power this system was discussed, but at this time it was decided that it was unnecessary. If the concerns about power failure at Poker Flat are raised before launch, the use of a generator should be reevaluated.

Interfaces

Data will be acquired from the following sources:

- Ground GPS system, RS 232.
- Telemetry Station, RS 422.
- Tracking Station (RF Power), RS 422.

Software

An integrated system for the capture of data from the serial inputs, archiving data to the hard disk and display of either real-time or archived data will be developed. The real time data flow diagram is shown in figure 3.6.2.1, and a basic flowchart of this data capture and display algorithm is shown in figure 3.6.2.2.

The data controller would allow the user to control the data stream, allowing the functionality shown in the example interface shown in figure 3.6.2.3. Not all of the functions would be available at all times – for example, the buttons in the lower left of the form do not make much sense when the data stream is set to real-time. This form also has a dropdown menu that allows the activation of the various data display forms that are available.

Data will be archived to the local hard drive in tab delimited ASCII format, and as binary files that contains the actual data stream as received at the telemetry station. This ASCII files can be easily imported into programs that allow manipulation of the data, and the binary files ensure that we retain the source stream that was used to generate the ASCII files.

The archiving system must ensure that a software failure or sudden loss of power does not lead to the loss of data already archived. A mechanism such as storing the data in multiple smaller files, or closing and reopening the data file regularly during archiving will be employed to ensure that archived data integrity can be retained.

It will be possible to save the graphs produced by this system as images, which can then be used in other documents or presentations.

3.6.3 Ground GPS Hardware

Functional Requirements

The ground GPS hardware provides data that can be used by the GPS software for differential corrections.

Interface

- Power: Standard 110 AC power outlet
- Data output: 9600 bps, RS232 serial stream.
- Connectors (2): power and data. The power connection is a Standard AC plug. The pin out for the serial connection is listed in table 3.6.3.1 below.

Table 3.6.3.1: Pinout for GPS serial connector

9 pin Serial			
1	NC	6	NC
2	Tx	7	NC
3	Rx	8	NC
4	NC	9	NC
5	Ground		

Design

The major ground station components are the receiver, the antenna, AC/DC adapter, PC, and the ground station board. See Jay Helmericks's Masters Thesis for a more complete description of the GPS system.

The ground station board serves as the necessary interface between the GPS, external power and the computer. The board has a five volt regulator so that any dc supply from 6.5v to 14v can be used. The power connector is a round power jack so that standard AC/DC converters can be used. The board can then be powered from any AC outlet. Currently a 9 volt 300 mA AC/DC converter powers the prototype board. The center post of the plug is ground and the outer shield is V+. The other major part of the board is the logic level to RS232 serial converter. This is a Motorola chip that takes the 0 to 5 volt serial stream from the GPS and converts it to RS232. This provides the necessary interface for a computer to collect the data. There are two LED's on the board that monitor +5v and the receiver pulse per second. Ths allows the visual monitoring of main power and receiver functioning. The receiver mounts to the ground station board and is electrically connected through a 20 pin 2mm female header. The receiver is physically mounted using four standoffs and bolts holding it securely in place. The schematic for the Ground station board is shown in Figure 3.6.3.1.

The antenna is a Micropulse 12700. This is a robust antenna that can be securely mounted using four bolts. The antenna has a TNC connection. RG-316 cable is used to run from the antenna to the MCX connection on the receiver. The antenna needs to be in a place with a good view of the sky. It is desired that the ground antenna sees all the satellites that the flight GPS sees that are above 5 degrees. The antenna must be placed at a known surveyed location, or allowed to collect data for several hours to fix its location. Once the location is fixed, the antenna can be removed and replaced, as long as it is put back in the same location.

Figure 3.6.3.1: Schematic for the Ground Station board

Assembly Notes

When the board is constructed the antenna hole must be cut out to the edge of the board. A hole is drilled during fabrication where the antenna plug goes in. This hole needs to be extended to the edge of the board for the antenna cable to follow.

To make sure that the receiver board is level and not bending the connecting pins a few washers will need to be added to the standoffs. The height of the pins doesn't correspond to a standard mounting height.

Component Testing

- Power up the board and verify 5v
- Check LED for receiver operation
- Check serial output and verify correct receiver operation

3.6.4 Ground GPS Software

Functional Requirements

- To process and display the GPS and DGPS data in real-time
- To process the display GPS and DGPS data in a post process mode
- Store real-time GPS data for future use.

Interface

The interface is a DOS program, so command line switches and hot keys control the operation of the program. Table 3.6.4.1 below lists the possible commands and their action.

Table 3.6.4.1: Program command keys and options

Command Line	
-real 'outfile1' 'outfile2' 'outfile3'	Runs the program in real time mode
-fix 'outfile'	The program will fix the antenna location over several hours

-disk ‘infile1’ ‘infile2’ ‘outfile’	Runs the program in post process mode
-archive [1/2] ‘outfile1’ ‘outfile2’	Runs program in save only mode
During normal operation	
‘S’	Starts and stops the saving of data
‘C’	clears the data currently on the screen
‘Q’	Quits the program
‘P’	Program GPS receiver

Design

The software reads the serial data from the GPS, optionally saves it to the hard-drive, decodes the packets and extracts the useful information, and then uses the extracted info to calculate the position of the receiver.

The program can run in several different modes to enhance the usefulness of the software. The first mode is real time. In this mode the data is coming in from the receivers through the serial ports. The data is saved, with a separate file for each GPS, and processed. The processed data is saved in another file for later use. The processed data and useful parts of the raw data are displayed on the screen. The second mode, disk, is similar to the first except is reads the input data from the hard-drive. The processed data is still saved to a file. Archive mode just saves the data and outputs useful raw data to the screen. This is mainly for collecting base station data to use in post process mode later. The archiver can be run collecting data from one or both serial ports. If only one port is used, it must be serial port one. The fix mode is used to fix an antenna location. It takes the position information and averages it over a maximum of 18 hours. The current position average is displayed on the screen as well as current raw data. When the program quits it outputs the antenna location in the output file.

The file format for the raw GPS data is binary. The data is a raw dump of the serial stream so that the header and checksum information is intact. The file format of the position data is text.

The calculation module takes the raw information output by the GPS receiver to calculate a double differenced solution. This removes the clock errors from both the receiver and the satellite. The solution is the difference in position between the two receivers, so the location of one of them must be known.

Operation Notes

Make sure that the save option is on if you want to save data

Testing

Basic position testing can be done by comparing the output with a fixed antenna position.

3.6.5 Integrated Testing & Assembly Plan

System Setup and Assembly

- Place Ground GPS antenna in known location, or allow time for antenna to acquire the location if the precise location is unknown
- Connect umbilical box to payload via umbilical cable
- Verify activation of payload systems from umbilical box
- Verify deactivation of payload systems from umbilical box
- Verify activation of EED board from umbilical box, ensuring that launch detect pin is inserted
- Verify deactivation of EED board from umbilical box
- Connect ground support blockhouse computer to umbilical box

- Activate onboard systems except EED board
- Retrieve and verify data from flight computer via umbilical box
- Connect telemetry station computer to UPS device
- Connect receiver station, ground GPS, and RF power inputs to telemetry station computer
- Receive and verify data from data inputs to telemetry station computer
- Remove power to UPS device
- Verify continued correct operation of telemetry station computer
- Reconnect power to UPS device and allow device to fully charge

3.6.6 Pre-Launch Activities

Immediately prior to launch, complete system setup and then complete these additional items:

- Reset flight computer.
- Verify flight computer data at blockhouse and telemetry station after reset.
- Ensure launch detect pin is inserted.
- Enable EED board.

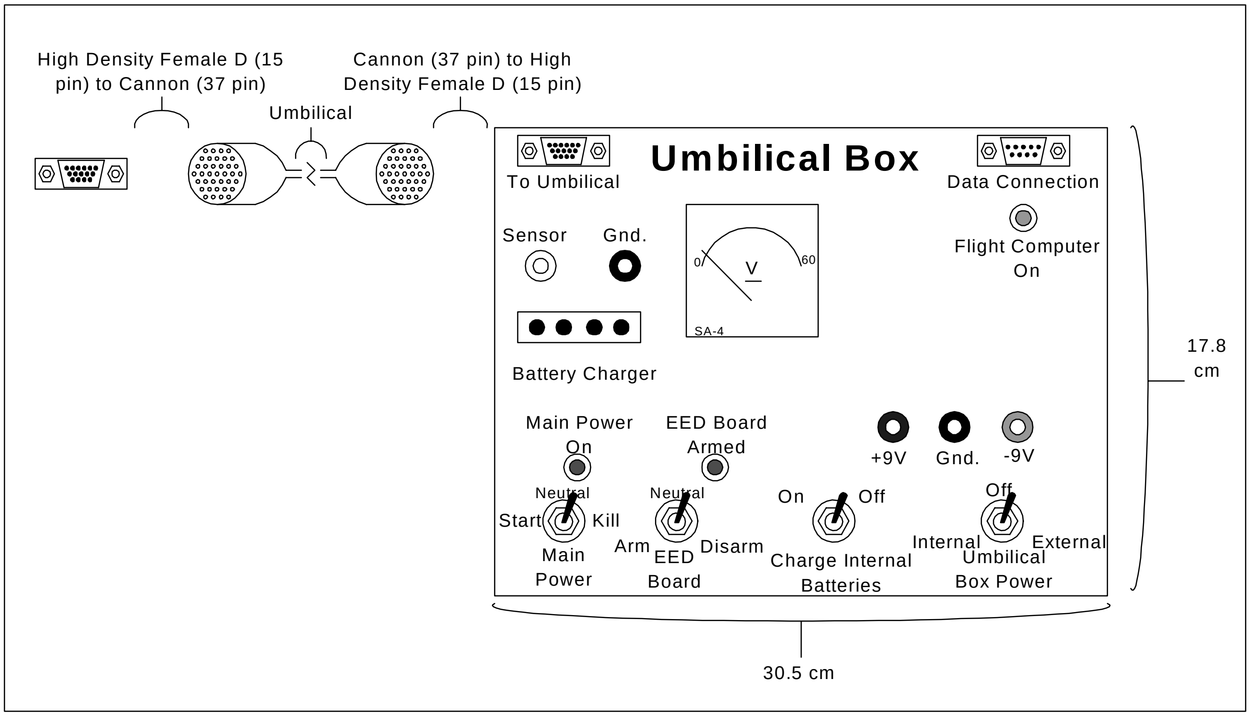

Figure 3.6.1.1: Umbilical Box layout.

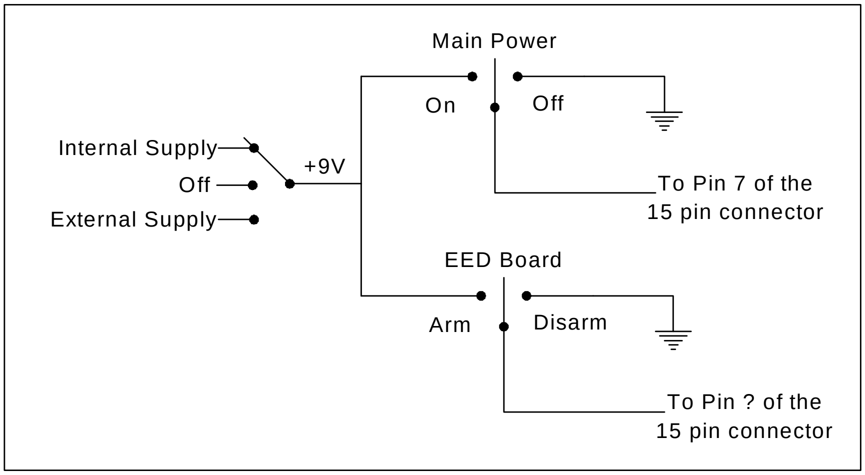

Figure 3.6.1.2: Umbilical Box: Main power and EED board switch.

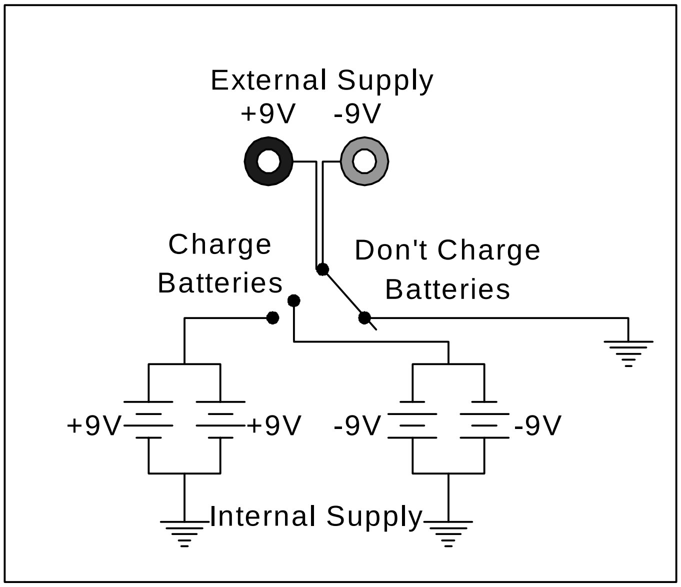

Figure 3.6.1.3: Umbilical Box: Internal power and external supply connections.

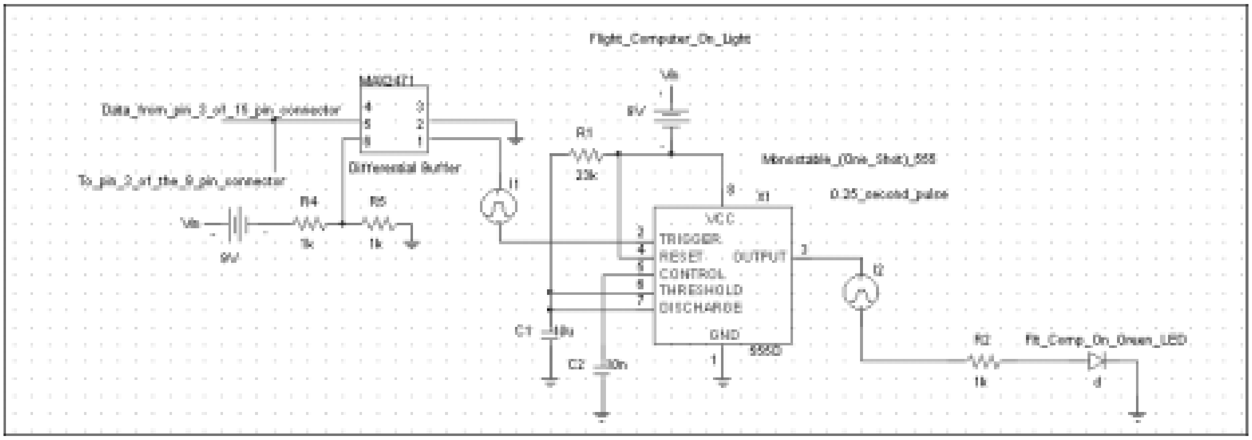

Figure 3.6.1.4: Schematic for “Flight Computer Functioning” LED.

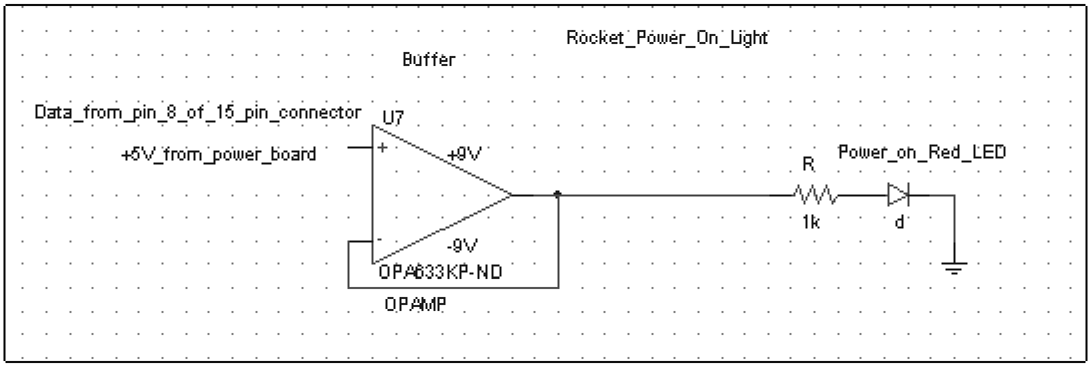

Figure 3.6.1.5: Schematic for “Rocket Power On” LED and “EED Board On” LED.

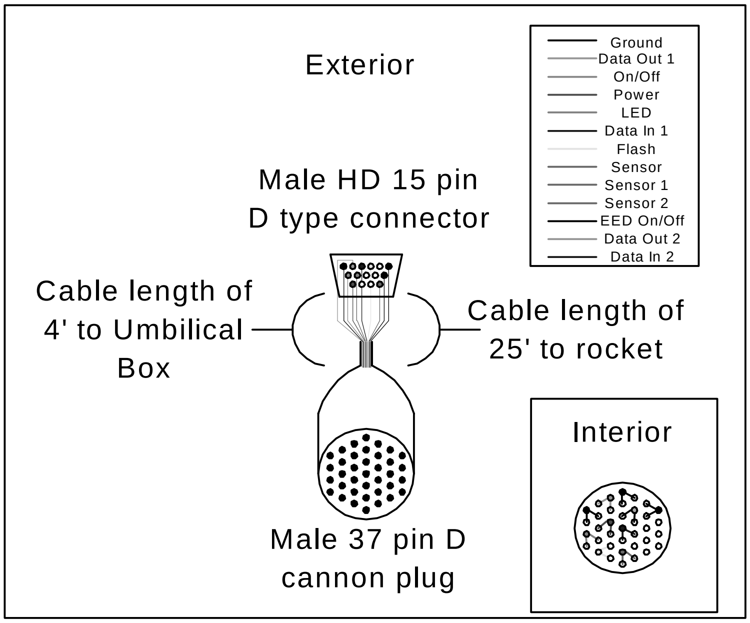

Figure 3.6.1.6: Cannon plug to HD 15 pin D-type adapter.

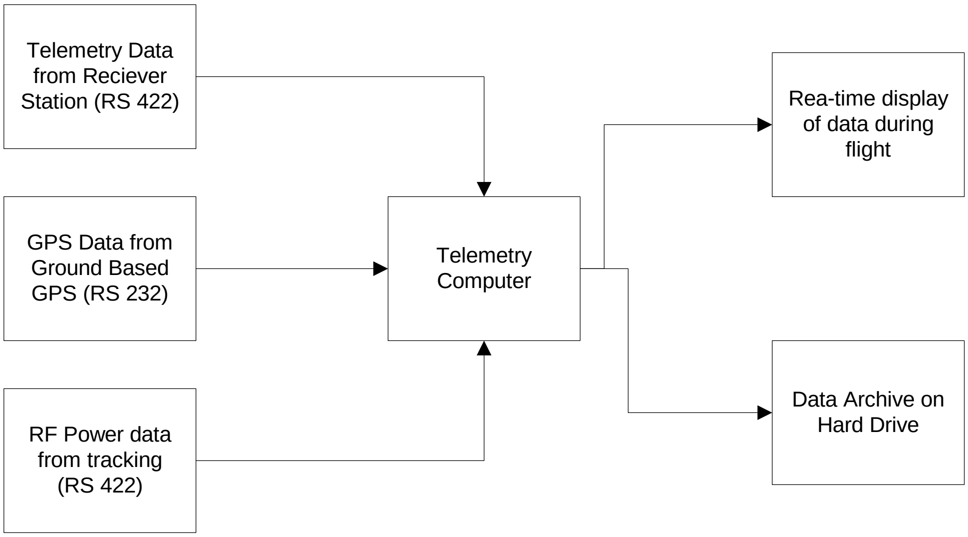

Figure 3.6.2.1: Data Flow Diagram for Ground Support Telemetry Computer

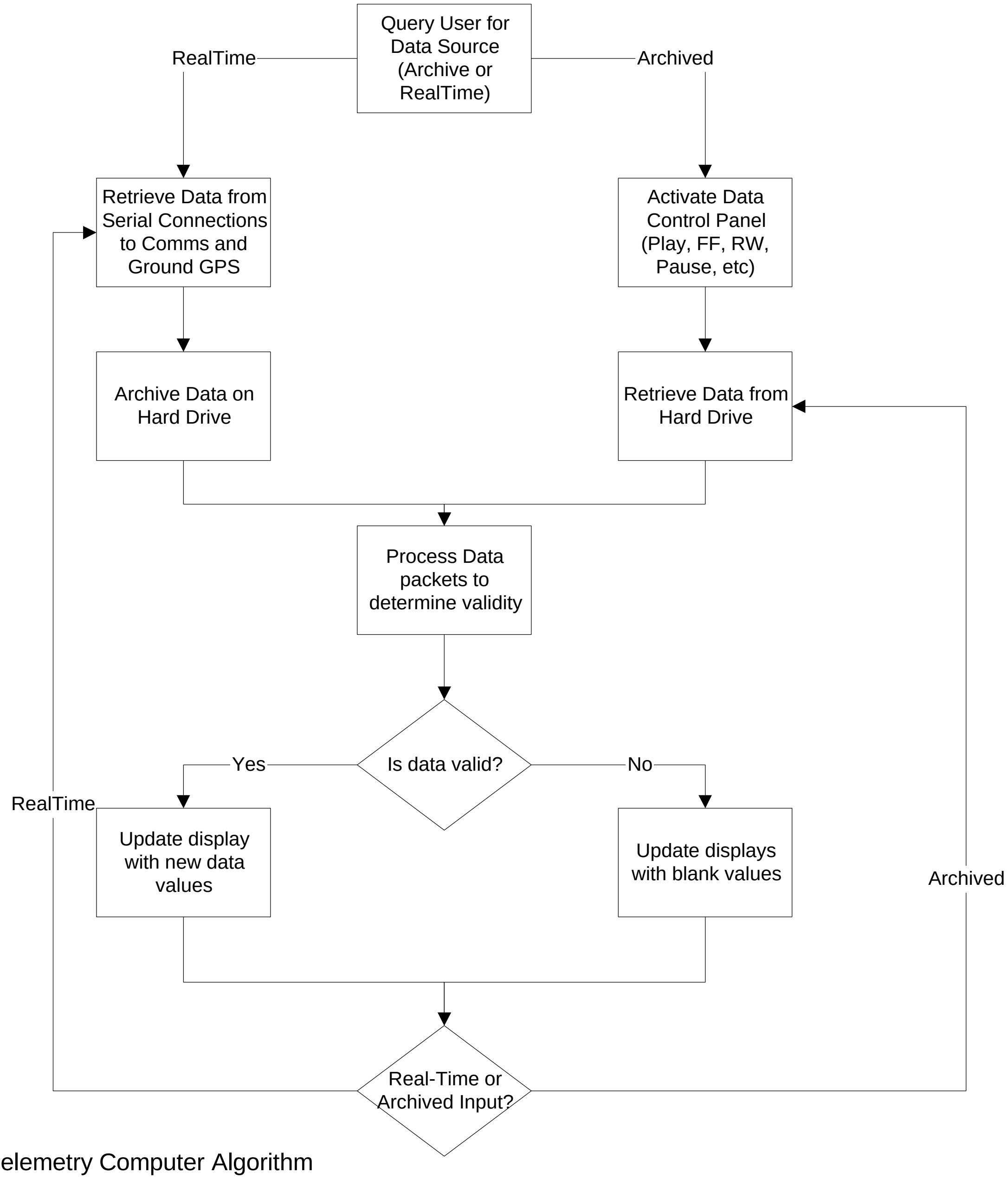

Figure 8: Telemetry Computer Algorithm


SRP4 Data Controller

Display Data

Data Source
● Archived Data ○ Real-Time Data

Archive Filename

Time
00:00.00

Figure 3.6.2.3: Telemetry Computer Data Control Interface

Table 3.6.1.1: D-type High Density (15 pin) Connector Pin Out (on Umbilical Box).

Pin	Function
1	Ground
2	Data to the flight computer (from 9 pin data connector pin 2)
3	Data from the flight computer (to 9 pin data connector pin 3)
4	Flt comp flash program switch (to 9 pin data connector pin 4)
5	Data to the flight computer (from 9 pin data connector pin 5)
6	Data from the flight computer (to 9 pin data connector pin 6)
7	On/Off for the power board (to pin 7 of the 15 pin connector)
8	Pwr in from the pwr board for 'Pwr ON' LED (from pin 8 of 15 pin conn)
9	On/Off for the EED board (to pin 9 of the 15 pin connector)
10	Pwr in from the EED board for 'EED ON' LED (from pin 10 of 15 pin conn)
11	Ground
12	Conn from batt charger (to rocket batts through pin 12 of 15 pin conn)
13	Charger sensor 1 (from pin 13 of the 15 pin connector)
14	Charger sensor 2 (from pin 14 of the 15 pin connector)
15	Sensor (from pin 15 of the 15 pin connector)

Table 3.6.1.2: D-type (9 pin) Connector Pin Out (Data).

Pin	Function
1	Ground
2	Data to the flight computer (through pin 2 of the 15 pin connector)
3	Data from the flight computer (from pin 3 of the 15 pin connector)
4	Flt comp flash program switch (from pin 4 of the 15 pin connector)
5	Data to the flight computer (through pin 5 of the 15 pin connector)
6	Data from the flight computer (from pin 6 of the 15 pin connector)
7	
8	
9	

Table 3.6.1.3: D-type High Density (15 pin) Connector Pin Out (On Rocket).

Pin	Function
1	Ground
2	Data to the flight computer (from pin 2 of the 15 pin connector)
3	Data from the flight computer (to pin 3 of the 15 pin connector)
4	Flt comp flash prog switch (to pin 4 of the 15 pin data connector)
5	Data to the flight computer (from pin 5 of the 15 pin connector)
6	Data from the flight computer (to pin 6 of the 15 pin connector)
7	On/Off for the power board (from pin 7 of the 15 pin connector)
8	Pwr in from the pwr board for 'Pwr ON' LED (to pin 8 of 15 pin conn)
9	On/Off for the EED board (from pin 9 of the 15 pin connector)
10	Pwr in from the EED board for 'EED ON' LED (to pin 10 of 15 pin conn)
11	Ground
12	Power from the battery charger (from pin 12 of the 15 pin connector)
13	Charger sensor 1 (to pin 13 of the 15 pin connector)
14	Charger sensor 2 (to pin 14 of the 15 pin connector)
15	Sensor (to pin 15 of the 15 pin connector)

3.7 EED Design

The EED board and its associated software have the responsibility of triggering the separation and parachute deployment mechanisms. Separation of the motor from the payload should occur below approximately 65,000m on the descent, at which point the payload section will begin to flat-spin. Deployment of the parachute should occur at below 6,100m on the descent. Furthermore, the EED board will be required to ensure safety in the EED system, so that the EEDs should not fire unexpectedly. If we assume that the vehicle follows its expected trajectory, then this functionality could be achieved solely through the use of timers. However, we cannot guarantee a nominal trajectory, and in the event that the flight path is unexpected we would like the EED system to act reasonably, with the goal of separating from the motor and allowing parachute deployment to take place in such a way that recovery of the payload is still possible.

3.7.1 EED Hardware

Functional Requirements

- To turn on and off independently of the rest of the payload
- To operate independently of the main power supply
- To fire all actuators needed
- To be as safe as possible

Interface for the EED Board

- **Power use:** estimated at 50 mA. The EED has it's own battery, so this is not drawn from the main battery pack. Standard Alkaline 9v have 500 mAh of capacity, so runtime is ~10h.
- **Weight:** estimated at 160 g for batteries, 80 g for the board.
- **Mounting:** The EED board will be in the standard SRP size.
- **Connectors:** Six total: two for EED fire lines, one for status out, one for data input, one for HC11 programming, and one for the on/off control. The pinout is in table 3.7.1.1 below. The status out connector is pinned for convenient routing to the HC11. The data in connector has 4 A2D inputs and for status switch inputs.

Table 3.7.1.1: EED board connectors

EED out			
1	eed1	5	eed3
2	GND	6	GND
3	eed2	7	eed4
4	GND	8	GND
EED out			
1	eed5	3	eed6
2	GND	4	GND
Status out			
1	stat8	5	stat4
2	stat7	6	stat3
3	stat6	7	stat2
4	stat5	8	stat1
Data in			
1	high pressure	5	launch
2	lon accel	6	sep

3	A2D extra1	7	deploy
4	A2D extra2	8	status4
Serial com			
1	GND	3	TXD
2	5v	4	RXD
Data con			
1	on/off	3	NC
2	EED on	4	GND

Design

The EED board is designed to be an autonomous component in the payload. This allows the EED events to continue as planned even if there has been a complete failure of the rest of the payload. If the rest of the payload does fail then the sensor redundancy will be lost, but the functionality of the board will remain. Figure 3.7.1.1 shows the electrical schematic.

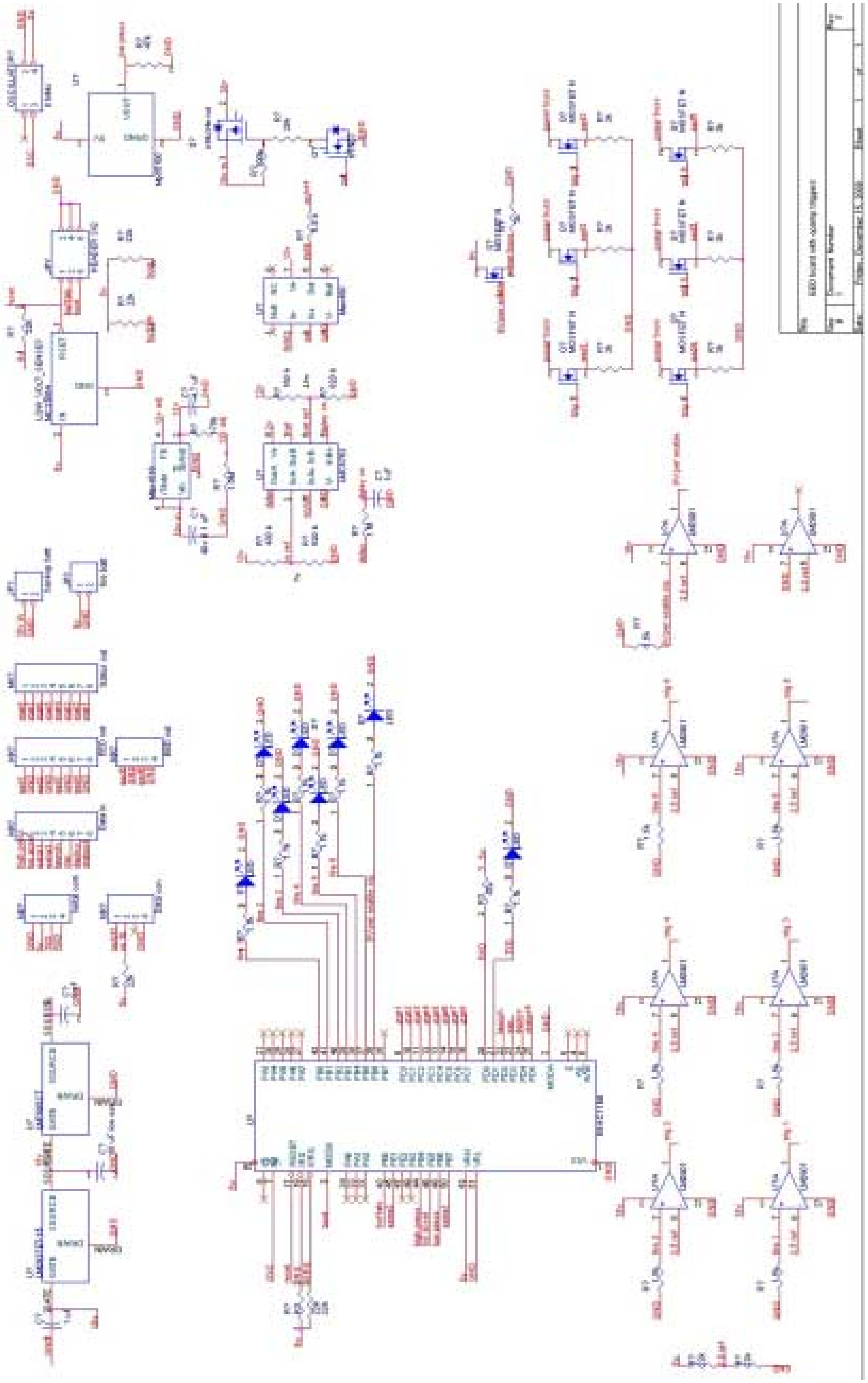

Figure 3.7.1.1: Schematic of EED board

Onboard batteries and regulators provide power for the board and for firing the EED devices. Main power for the board is from two 9v alkaline batteries in series to provide 18v. The expected run time, based on a 50 mA operating current, is 10 hours. Five and fifteen volts are regulated from the battery. Due to the small difference between the battery and 15v, a low dropout regulator from National is used. The five volt regulator runs off of the 15 v regulator to minimize the voltage drop and power dissipated in the regulator. The EED firing batteries are nominally two 9v alkaline in parallel. This will need to be re-evaluated and tested once the actual EED devices are known. This battery goes straight to the EED switches, so the switching FET's set the maximum voltage and current that can be tolerated.

A latching switch is integrated onto the board so that it can be powered up independently of the rest of the payload. This prevents an accidental arming of the EED board during handling and testing of the integrated payload. The EED board would remain powered off until right before launch.

The latch is designed to be as immune to noise as possible. In operation the latch requires a signal greater then 7 volts for about 2 seconds to turn on or off. Any DC voltage less then 7 volts or symmetric AC signals with a DC average less then 7 volts between 5 and 30k Hz will be rejected. It is not immune to low frequency AC signals that remain above 7 volts for the setup time, or high frequency AC signals above 7 volts because they are too fast for the low power op-amps. The input impedance of the on/off line is 6.8 kΩ.

A micropower 12v regulator provides power from the battery for the latch. The regulator was used to prevent the changing battery voltage from affecting the switching voltage of the latch. Two comparators are used in the switch and one op-amp in the latch. The first comparator compares the input voltage with seven volts set by a resistor divider and turns on if the input voltage is above the reference. The output charges and discharges a capacitor through a large resistance. This is what sets the delay. The second comparator compares the voltage of the capacitor to a second voltage divider set at ten volts. When the voltage on the capacitor exceeds ten volts the comparator turns on, which turns on the power FET. The op-amp buffers the output of the second comparator and feeds it back to the input of the first. This latches the switch on. The buffer is included to prevent the input from directly affecting the signal controlling the power FET, and to minimize the input impedance of the latch.

The smarts of the board is a HC11E9 microcontroller. The program on the HC11 monitors sensors and status switches and outputs status information and fire signals at the appropriate time. Four lines are routed to port D for 0-5volt status switches. Three are assigned for launch, separation, recovery deployment, and one is left for future use. Five lines are routed to the A2D's on port E. One is tied to the air pressure sensor mounted on the board. The other four are routed to a connector for external use. Two monitor the air pressure sensor on the instrumentation board, and the longitudinal accelerometer on the accelerometer board. Two are left for future use. Port C is designated as status information and routed to a connector. Two of these lines will be used to tell the flight computer when the EED's are fired for separation and recovery deployment. The rest of the lines can be used for diagnostic information during testing and software development. The lines could also be used as general digital inputs if a need arose, since the port can be configured as an input or output. Port B is used for the EED fire lines. A logic high turns on the firing circuit connected to that pin. All the fire lines are connected to LED's for a visual indication of firing during testing. Each of the output lines are also connected to ground through a resistor so no stray voltage will trigger the fire circuit. The HC11 has to actively drive the pin high to initiate firing. The serial lines of the HC11 are routed to a connector for communication with a computer. The pinout of the connector is the standard pinout for the logic level to RS232 converter that is in the lab.

Each firing circuit consists of an comparator and a power FET. The comparator takes the five volt signal from the HC11 and steps it up to about 13 volts. The comparators are referenced to 2.5 volts so they rail high and low based on the signal from the HC11. The output of the comparator drives the gate of the power FET that switches power to the EED device. There are six firing circuits. The battery used fire the EED devices is switched on and off by a seventh FET. This last FET is a safety measure, requiring two circuits to go high to fire an EED. The output of all seven FETs have a 3k ohm bleeder resistor to prevent any charge from building up on the EED output lines.

It is worth noting that the comparators are the only electronics running off of the 15v regulator, and because they rail high side, the regulator output sets the voltage passed to the FET's. The FET's do not require 13 volts to turn fully on, only about 5-8 volts, so the EED board will still be able to fire until the battery voltage falls below about 11 volts.

A summary of the hardware safety measures:

- The board is powered on and off separately from the rest of the payload
- Power used to fire the EED's is switched by the HC11
- The fire lines from the HC11 are tied to ground with a resistor
- The EED outputs are tied to ground with a resistor

Assembly Notes

- Low ESR capacitors must be used for the output of the LDO 15 volt regulator and the micropower 12v regulator.
- Be sure to label the boot, reset, and buffalo jumpers.

Testing

- The firing battery needs to be chosen and tested after the details of the actual devices to be fired are available.
- Attach main and backup power supplies to the EED board
- Load test program to HC11. This program will cycle through the EED lines firing each one. This will be done once with the EED power enabled and once with it disabled. This will verify that they can't fire with the power rail disabled.
- Attach EED equivalent load to EED output
- Attach scope to output lines
- Run test program and verify that all EED lines fire properly
- Attach hand vacuum pump to air pressure sensor and verify operation

Future improvements

One improvement is adding a continuity check to the board. This would allow the HC11 to check and see if there is a device connected to the output of each EED circuit. A small current on the order of 1 mA would be used so that there is no chance that the EED would be fired during the check. This information could be output to the flight computer for verification that EED's are properly connected before launch.

3.7.2 EED Software

Requirements

The EED board software is responsible for arming and firing the electro-explosive devices that cause the payload separation and parachute deployment to occur. The software should of course act correctly in the case of a nominal trajectory, but should also attempt to allow the separation and recovery of the payload in the case of failure of instrumentation or the rocket motor.

Algorithm

The algorithm for the EED board software is shown in figure 3.7.2.1, and consists of the following steps

- When activated, the board waits until the readings from the sensors can be expected to have stabilized, and then takes some baseline readings from the sensors (longitudinal accelerometer, low altitude altimeter, and high altitude altimeter). These readings will be used immediately after launch to gauge the health of each sensor.
- The board waits for the launch signal, and when it is detected a timer is started. Launch will be signaled by the removal of the umbilical connection as the vehicle leaves the launch rail. In order to guard against a misdetection of launch due to the unexpected removal or disconnection of the umbilical connection while the vehicle remains on the launch rail, the EED board will not be powered up with the other on-board systems, but will be powered up by a separate command sent from the umbilical box immediately prior to launch. This ensures that even if the umbilical connection is disconnected during pre-launch activities, the EED board software will not assume a launch has occurred and begin to proceed through the list of EED board activities (arming, separation, and parachute deployment) while the vehicle remains on the ground.
- During the first three seconds following the launch detection, readings are taken from each of the sensors at 100ms intervals, and the results are used to sets flags that signify whether the sensor is operating as expected. This determination will be made by looking for a reasonable progression in the readings, rather than looking for specific values to be reported, since even during this stage the vehicle may not be following a nominal trajectory. The altimeters should report an increasingly positive altitude relative to the baseline value, and the longitudinal accelerometer should report a large positive value initially, followed by decreasingly positive thrust readings. Based on the current models of the SRP4 flight as of 12/4/00, figures 3.7.2.2 and 3.7.3.3 show the progression of altitude and longitudinal acceleration that are expected for a nominal flight. The data behind these graphs is shown in table 3.7.2.1.
- The first action to be taken is the arming of the EEDs. Readings will be taken from all of the operational sensors (longitudinal accelerometer, and both altimeters) in parallel at 100ms intervals, which will be the sample interval for all readings during the flight. The predicted accelerometer data for burnout is not available from the model at this time. The predicted altitude at burnout is 22439m (73600ft), so the EEDs will arm above 22500m (73800ft). The predicted time to burnout is 32.5 seconds, and the timer will trigger the arming action at 35 seconds after launch. The arming action will occur when any one of the following occurs:
  - The operational longitudinal accelerometer reports three consecutive large negative acceleration readings – the actual number is not available from the model at this time.
  - The operational low altitude altimeter reports 3 consecutive readings in excess of 22500m (73800ft).
  - The operational high altitude altimeter reports 3 consecutive readings in excess of a 22500m (73800ft).
  - 35 seconds after launch has been reached on the timer.

- The second action to be taken is the firing of the EED to separate the payload from the motor, which should occur at below 65,000m on the descent. The requirement for the separation to occur at this altitude was set immediately before the production of this document, and a strategy for triggering this event has not been determined. It was hoped that the high-altitude altimeter would allow accurate altitude readings at above 65,000m, but that has been also called into question.
- The final action to be taken is the firing of the EED to deploy the parachute, which should occur at approximately 6100m (20,000ft). Since the separation point changed immediately prior to the production of this document, there is no timing data for this event. This event will be triggered by any of the following events:
    - The operational low altitude altimeter reports 3 consecutive readings of less than 6100m (20,000ft).
    - The operational high altitude altimeter reports 3 consecutive readings of less than 6100m (20,000ft)
    - A predetermined time period has expired.

EED firing procedure

The procedure for firing the separation EED is as follows:

- A sequence of three fire signals will be sent to the separation EED, separated by short time intervals in the range 5ms-20ms.
- The EED board will allow a five second period for the separation status switch to show that successful separation has occurred.
- If less than three separate firing sequences have been sent to the separation EED while the separation status switch continues to show that separation has not occurred, loop to i).
- Otherwise, the separation status flag shows that separation has occurred or it can be assumed that either the separation status flag is faulty or that continued sending of the EED signal is unlikely to cause separation. In these cases, there will be no further attempts to fire the separation EED.
- The firing procedure for the parachute deployment EED is as follows
- A three firing signal sequence will be sent to the deployment EED, again with the signals separated by short time intervals in the range 5ms-20ms.
- The EED board will allow a five second period for the deployment status switch to show that successful separation has occurred.
- These two steps will be repeated until the deployment status switch shows that deployment has occurred or the battery loses power.

Testing

- The basic algorithm to be used to can be implemented on a non-embedded system, where predetermined sensor input sequences can be read from files. This will allow testing, and possible modification, of the proposed algorithm under various conditions, such as faulty sensors or and a variety of flight trajectories
- The code can be loaded onto the EED board, with the outputs connected to LEDs rather than the EED devices, and the inputs given simulated data. This will ensure that the board will send signals to the EEDs under various input conditions.
- The EED board inputs can be connected to the actual sensors to be used on the flight, and the sensors can be made to return values that will test the behavior of the board under various conditions, including anomalous sensor readings.
- The launch detect ability of the EED board should be tested, including situations where the launch detect pin does not detach on launch.

- The EED board should be connected to the umbilical cable, and it should be verified that the board can be activated and deactivated from the umbilical box.
- The EED board should be connected to the status switches, and it should be verified that the EED board is correctly reading the data from the status switches.

Pre-Launch Configuration

- The EED board should be connected to all input devices, including the separation and deployment status switches, the high altitude altimeter, and the longitudinal accelerometer. The low altitude altimeter is on the EED board and therefore will already be connected.
- The EED board should be deactivated from the umbilical box at all times prior to immediately before launch.
- It should be confirmed that the launch detect pin is properly inserted into the vehicle.
- The EED board should be activated a short period before the launch (~30 seconds) and the umbilical box should report that the EED board is in an active state.
- The EED board should be immediately deactivated if the launch is delayed.

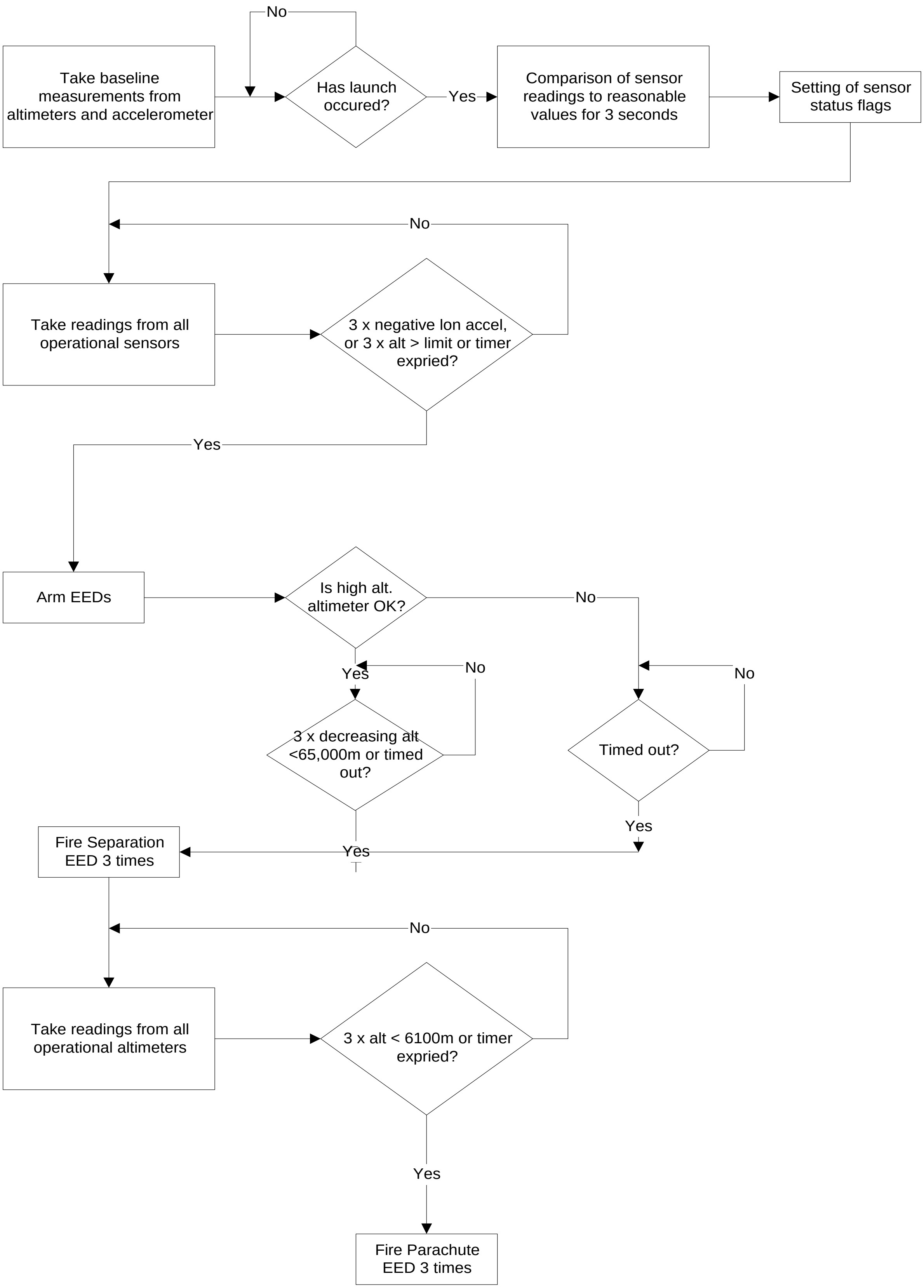

Figure 3.7.2.1: EED Board Software Flowchart

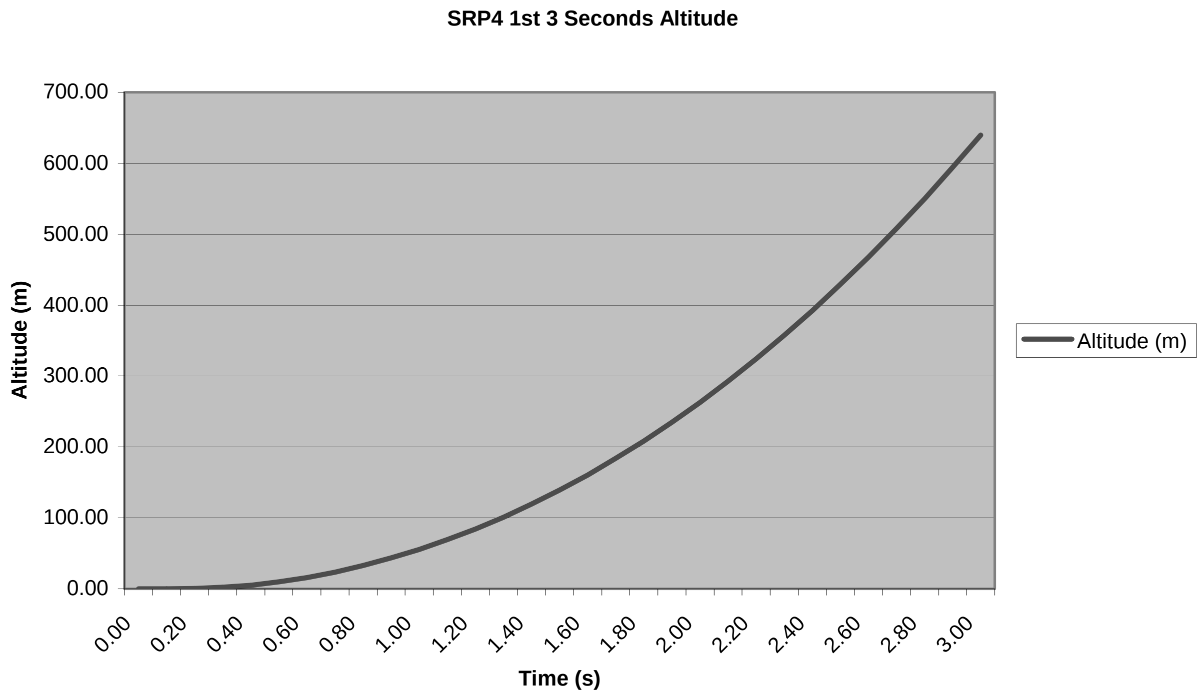

Figure 3.7.2.2: Projected altitude for the first three seconds of the SRP4 flight on nominal trajectory

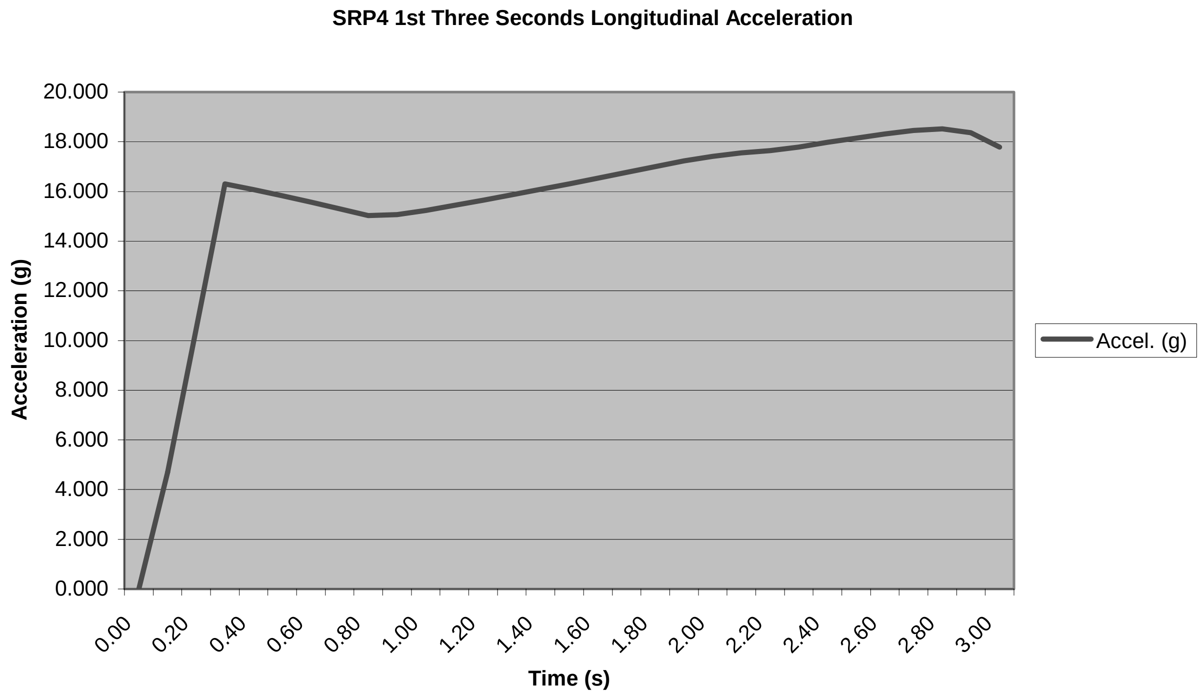

Figure 3.7.2.3: Projected acceleration for the first three seconds of the SRP4 flight on nominal trajectory

Table 3.7.2.1: Projected Data for first three seconds of SRP4 flight

TIME (sec)	Accel. (ft/sec2)	Accel. (m/s2)	Accel. (g)	Altitude (feet)	Altitude (m)
0.00	0.000	0.000	0.000	0.00	0.00
0.10	151.421	46.165	4.706	0.17	0.05
0.20	336.483	102.586	10.457	1.86	0.57
0.30	524.605	159.941	16.304	6.92	2.11
0.40	516.980	157.616	16.067	16.89	5.15
0.50	509.078	155.207	15.821	32.04	9.77
0.60	500.890	152.710	15.567	52.27	15.94
0.70	492.420	150.128	15.304	77.51	23.63
0.80	483.668	147.460	15.032	107.68	32.83
0.90	484.755	147.791	15.065	142.69	43.50
1.00	490.147	149.435	15.233	182.55	55.66
1.10	496.684	151.428	15.436	227.32	69.30
1.20	503.517	153.511	15.648	277.05	84.47
1.30	510.445	155.623	15.864	331.82	101.16
1.40	517.471	157.766	16.082	391.69	119.42
1.50	524.643	159.952	16.305	456.73	139.25
1.60	531.937	162.176	16.532	527.03	160.68
1.70	539.347	164.435	16.762	602.64	183.73
1.80	546.884	166.733	16.996	683.64	208.43
1.90	554.544	169.068	17.234	770.12	234.79
2.00	560.321	170.830	17.414	862.14	262.85
2.10	564.882	172.220	17.556	959.77	292.61
2.20	567.622	173.055	17.641	1063.04	324.10
2.30	572.290	174.479	17.786	1172.00	357.32
2.40	578.398	176.341	17.976	1286.68	392.28
2.50	583.985	178.044	18.149	1407.14	429.01
2.60	589.421	179.702	18.318	1533.44	467.51
2.70	593.946	181.081	18.459	1665.64	507.82
2.80	595.701	181.616	18.513	1803.77	549.93
2.90	590.946	180.166	18.366	1947.86	593.86
3.00	572.057	174.408	17.779	2097.85	639.59

Table 3.7.2.2: EED Board Software Labor

Activity	Time
Non-Embedded Prototype (development)	~15hrs
Non-Embedded Prototype (testing)	~20hrs
hc11 version (development)	~20hrs
hc11 version (testing)	~20hrs
Total Labor	~75hrs