User Guide

HAB PILOT
Satellite Balloon Flight Computer

Balloon Ascent Technologies

The sky's not the limit; it's where we start.

Overview

The *HAB Pilot* is a stand-alone balloon flight computer that:

- Controls other Loonatec HAB Modules such as the HAB Ballaster & HAB Venter

- Command & telemetry via the Iridium satellite network for world-wide coverage

- Built-in flight termination: can activate both squibs (pyrotechnic) and burn-wires (thermal)

- Monitors flight conditions: GPS, pressure, accelerometer, magnetometer, and clock sensors and can respond autonomously, sending pre-programmed commands

Pilot Operating Specifications

Parameter	Min	Typical	Max	Unit
Operating: Temperature	-80	-	60	°C
Operating: Time (w/ 3x L91 batteries)	8	16	36	hours
Operating: Heater Set Point	-60	-10	60	°C
Operating: Internal Power	3x Li/FeS2 AA Batteries			
Operating: External Power	2-5 VDC, < 0.5 amps			
Sensor: Pressure	8	-	1200	mBar
Sensor: Temperature	-60	-	120	°C
Sensor: GPS Altitude	-	-	50,000	meters
Sensor: Accelerometer	-	-	16	g's
Sensor: Magnetometer	-	-	-	degrees
Mechanical: Mass (no Enclosure or Batteries)		85		g
Mechanical: Mass (incl. Batteries)		130		g
Mechanical: Mass (incl. Enclosure & Batteries)		150		g
Mechanical: Size in Foam Enclosure	130 x 110 x 85 mm			
Mechanical: Size without Foam Enclosure	90 x 70 x 35 mm			

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1   Pre-Flight Checklist

Perform the following steps up to 24 hours in advance of launch:
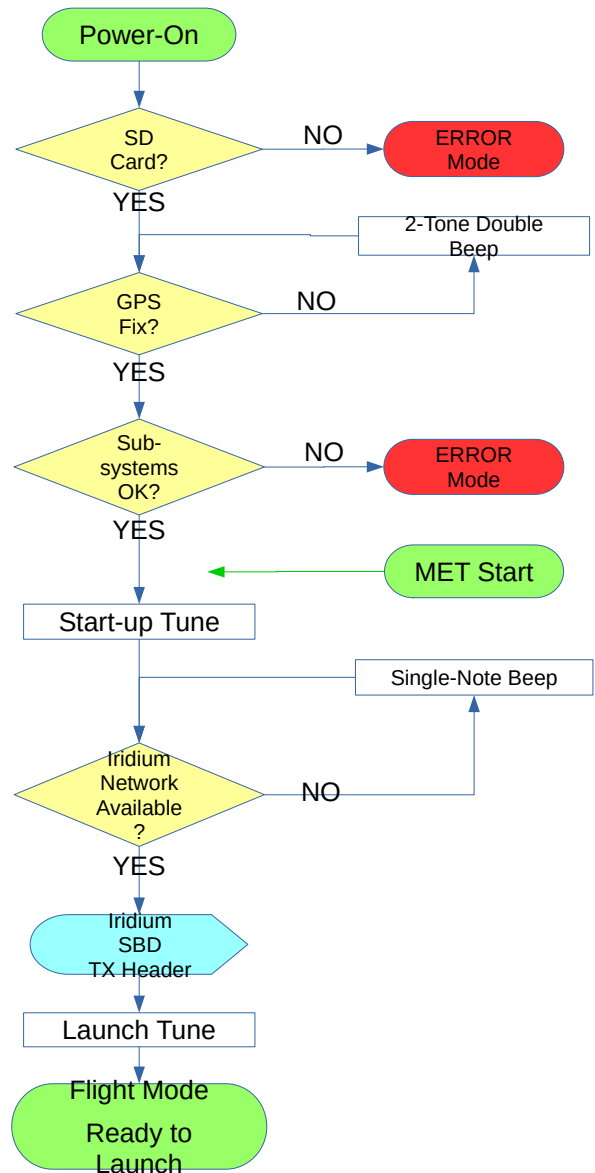
1) Insert batteries

2) Rig into flight train

Perform the following steps 30-60 min before launch

1) Go to the launch area with an unobstructed view of the sky

2) Place foam enclosure upright

3) Switch the HAB Pilot's Power-On switch

4) Listen for the 2-tone double beep indicating waiting for a GPS fix

5) Turn on any other HAB Modules that are controlled by the HAB Pilot

6) Listen for the Start-up tune to indicate GPS fix has been acquired

   <mark>NOTE TIME → this is MET = 0</mark>

7) Verify that the HAB Modules' blue BLE LED changes from 2-4 Hz to a slow flash rate depending on Flight.cfg setting

8) Wait for data header to be transmitted via Iridium SBD

   <mark>DO NOT LAUNCH until message sent</mark>

9) Listen for Launch Tune to play, followed by silence

10) Verify that header data has been received by the Mission Control software

11) Verify HAB Pilot's white Status LED is flashing at 4 Hz.

12) Unit is now ready to be flown—place in foam enclosure and seal with tape

Power-On

SD Card? — NO → ERROR Mode

YES

2-Tone Double Beep

GPS Fix? — NO

YES

Sub-systems OK? — NO → ERROR Mode

YES

MET Start

Start-up Tune

Single-Note Beep

Iridium Network Available? — NO

YES

Iridium SBD TX Header

Launch Tune

Flight Mode Ready to Launch

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2   Interface

Iridium SBD

The following ASCII formatted commands are permitted:

SleepMode: Allows the Iridium SBD modem to go into a low-power mode when not actively transmitting. Results in up-link commands not being received until a down-link data message is sent.

AwakeMode: Keeps the Iridium SBD modem in a powered-on mode to receive Ring Alerts. Should result in up-link commands being received promptly but uses more battery power.

Report #: Changes the *HAB Pilot's* down-link data message transmission rate. Number argument is in seconds. It is suggested to use a minimum report rate of 300 seconds (5 minutes) for optimal Iridium performance.

Shutdown: Turn the *HAB Pilot* OFF. If the Power-On switch is still in the 'ON' position then the HAB Pilot will restart.

LoCFS #: Sets the Loss-of-Comm-Failsafe timer to n seconds and starts counting down. A value of "-1" will disable the LoCFS timer. When the timer expires the Terminate command, if configured, will be activated.

Command Name: Any command in the Flight.cfg file can be activated by sending its name. Example: sending "PwrOnTest" (see Command Section)will cause the "Command: PwrOnTest{}" in the Flight.cfg file to be activated again, regardless of any "Conditions{}" set.

HAB Module: A command can be relayed to any HAB Module that is configured in the Flight.cfg file (see Configuration Section)by sending the module's name, a space, and the desired command. Example: sending "`!cutr1 sd=Y`" will shutdown the module with the name `!cutr1`.

micro-SD Card

The *HAB Pilot* creates a new directory each time it is powered on. Inside of this directory are the following files:

- Flight.CSV – Contains comma-separated data recorded at up to 2 Hz
- Flight.KML – Contains position data in a format that programs like Google Earth use
- Flight.LOG – Contains a time-stamped system log for post-flight analysis

Power-On Button

Pressing this button will turn the *HAB Pilot* on. Repeated pressing or constant pressing will have no impact on the *HAB Pilot's* operation. It can not turn off the *HAB Pilot*.

To shutdown the HAB Pilot, either issue the Iridium SBD command or remove one of the batteries.

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Audio Tunes

GPS Wait: the HAB Pilot will play a 2-tone beep briefly once every two seconds to indicate that GPS position fix has not yet been obtained and should not be launched.

GPS Lock: Once the HAB Pilot acquires GPS lock the intro to Bach's Toccata and Fugue in D Minor will play to indicate a successful self-check power-on sequence.

Data Header Wait: the HAB Pilot will play a 1-tone beep briefly once every two seconds to indicate that the data header has not yet been transmitted and that the HAB Pilot should not be launched yet.

Launch Tune: Once the HAB Pilot has successfully transmitted the data header message the intro to Beethoven's Für Elise will play to indicate that the HAB Pilot is ready to be launched.

ERROR Tune: If an error is detected during the power-on sequence, a continuous rapid 2-tone sound will be played. The HAB Pilot is unusable while this rapid continuous beeping is sounding.

Cutter Activation Tune: A single note will be played twice in the following pattern: two-second tone, two-second silence, two-second tone, two-second silence, cutter activation.

Status LED

The *HAB Pilot* has one white Status LED. Possible blink patterns are:

While acquiring GPS lock it will will alternate at 1 Hz.

In normal operations the status LED will flash at 4 Hz.

If there is an error, the STATUS LED will flash rapidly, indicating that the *HAB Pilot* is unusable until the error is corrected.

Error Mode

The *HAB Pilot* will enter Error Mode if any of the following problems are encountered:

- micro-SD Card Problem—No card present, incorrect formatting, or no available space

  - A no-card-present failure will be indicated by entering Error Mode before GPS fix is acquired.

  - An incorrect formatting or no available space failure will be indicated after GPS fix is acquired and indicated in the Flight.log if possible.

- Cutter Continuity Problem—One or more of the enabled cutters failed a continuity test

- Sensor Problem—An issue was detected with an onboard sensor

- GPS Problem—An issue was detected with the onboard GPS sensor

Check the Flight.LOG file for an indication of which subsystem failed. Note: if the Flight.LOG does not exist then there is an issue with the micro-SD card itself.

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3 Programming

The *HAB Pilot* is programmed via the "config/Flight.cfg" file. The following is an explanation of the various options in that file.

Configuration Section

This section is used to configure the *HAB Pilot* and its subsystems. The following is an example of the default settings for a v2 HAB Pilot.

```
Version: 1
HeaterEnableTemp: -20
LoCFS: -1
# -- LoRa HAB Radio Settings
CommDevice: Lora, 915, 125, 9, 7, 18, 2, 8
# -- Wired HAB Module Settings
# CommDevice: HabBus, 115200
# -- HAB Module Settings
HAB: !cutr1, LoRa, A, 120, 600
# HAB: !cutr2, LoRa, B, 30, 100
# HAB: !blst1, HabBus, C, 300, 1000
# HAB: !blst2, HabBus, D, 400, 2000
# HAB: !vntr1, LoRa, E, 30, 100
# -- Iridium Settings
CommDevice: Iridium, 1, 19200, 300
CommData: Timestamp, System, Position, AccMag, Ambient, !cutr1
CommBinary: true
CommHeader: true
# -- SD Data Settings
SDCardData: Timestamp, System, Position, AccMag, Ambient, !cutr1
SDCardRate: 2
# -- Squib/Burn-wire Settings
CutterControl:
```

Note: any line that begins with a '#' character is considered a comment and ignored. The lines are colored green for ease of identification in this document but may not be in your text editor.

- <u>Version</u> → A user configurable version number for tracking *Flight.cfg* changes in the *Flight.log* files.

- <u>HeaterEnableTemp</u> → Temperature at which the HAB Pilot's battery heaters turn on

  - **-20** → Heater set point, in degrees Celsius

- <u>LoCFS</u> → Configures the Loss-of-Comm-Failsafe timer subsystem

  - **300** → LoCFS timer period:

      -1 → timer not activated upon boot, requires an incoming command to start

      300 → timer starts at boot with a value of 300 seconds (5 minutes)

          Accepts values of 1 to 32,000 seconds

- <u>CommDevice</u> → The settings to enable LoRa-based HAB Module communication

  - **LoRa** → Use the LoRa radio communication link

  - **915** → LoRa frequency, in MHz   valid range is 862.0 to 1020.0 MHz

  - **125** → LoRa bandwidth, in kHz
      Valid options are: 7.8, 10.4, 15.6, 20.8, 31.25, 41.7, 62.5, 125, 250, or 500 kHz

  - **9** → LoRa Spread Factor   valid range is 6 to 12

  - **7** → LoRa CR   valid range is 5 to 8

  - **18** → LoRa Sync word, in decimal
      Default is 18 (0x12), 52 (0x34) is reserved for LoRaWAN

  - **2** → LoRa Transmit Power, in mW   valid range is -3 to 15

  - **8** → LoRa Preamble   valid range is 6 to ?

- <u>CommDevice</u> → The settings to enable wire-based HAB Module communication

  - **HabBus** → Use the opto-isolated serial communication link

  - **115200** → Serial baud rate   valid range is 1200 to 115200 baud
      Note: must match the HAB Module(s) baud rate, set with the **!iSU** command.

- <u>HAB</u> → The settings for a specific HAB Module

  - **!cutr1** → Module name, must start with '!' and be unique

  - **LoRa** → Communication method, either **LoRa** or **HabBus**
          This communication method must already be declared by a CommDevice call

  - **A** → Module's identification letter, set with the **!iSI** command

  - **120** → Interval at which to poll module at, in seconds

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- **600** → Value to set the module's WDT to, in seconds
  The value is optional, if not specified then the module's WDT is not enabled
  If used, normally a little greater than three times the polling interval

- <u>CommDevice</u> → The Iridium SBD serial connection settings. Arguments:

  - **Iridium** → Name of the port type [not user selectable]

  - **19200** → Baud rate [default is 19200]

  - **300** → Output interval in seconds, user selectable (300 to 1800 are common)

- <u>CommData</u> → The collection of data sets to be transmitted via the Iridium SBD modem. Arguments:

  - **Timestamp** → GPS timestamp and *HAB Pilot's* Mission-Elapsed-Timer (MET)

  - **Position** → Longitude, Latitude, Altitude, Heading, Ground Speed, Vertical Speed

  - **AccMag** → Acceleration in XYZ, Aggregate acceleration, Magnetometer in XYZ, and RPM

  - **Pressure** → Pressure, rate of pressure change, and humidity

  - **System** → System data such as Battery Voltage, Status flags, and Cutter info

  - **GPS** → Either the raw NMEA GGA (ASCII) or the UBX-NAV-PVT message (binary)

- <u>CommBinary</u> → Whether to transmit binary or ASCII data over the Iridium SBD modem

  - Arguments: true or false

- <u>CommHeader</u> → Whether to transmit an ASCII header at power-on to aid in decoding the subsequent binary or ASCII data

  - Arguments: true or false

- <u>SDCardData</u> → The collection of data containers to be logged to the SD card's *Flight.csv* file. See SDCardData above for container options.

- <u>SDCardRate</u> → Record every x sensor cycles (2 Hz)
  A value of 1 results in 2 Hz data, while a value of 2 results in 1 Hz data.

- <u>CutterControl</u> → Enables the cutter control subsystem to activate squib(s) or burn-wire(s). No arguments, configuration occurs in the *Action* section of each programmed *Command*.

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Command Section

The *HAB Pilot* can be configured to have a reasonable number of commands. The actual allowable number of commands is dependent on their complexity—RAM usage. The *HAB Pilot* will enter into the Error Mode and report the issue in Flight.log if too many commands are attempted at startup.

Each of these commands is acted upon independently by the conditions set and results in the various actions being executed. The name, **PwrOnTest** in the below example, is user configurable and used to identify the command activation in the Flight.log and Flight.kml files.

The **PwrOnTest** command, shown below, will result in the following:

1) Activate once, 30 seconds after GPS fix is acquired

2) Play a G5 note twice of duration one second, separated by one second delays

3) Sends the command **!iSH** (query heater set point) to all of the **!cutr** HAB Modules

4) Logs all of the **!cutr** HAB Module replies in the Flight.log file so each of their heater set points is recorded for the flight

```
Command: PwrOnTest
{
  Conditions:
  {
    Trigger:
    {
       Compare: Timestamp.MET   = 30.000000
    }
  }
  Actions:
  {
    PlayTone: 784, 1.00, 1.00, 2
    HAB: !cutr*, SH
  }
}
```

The **Terminate** command, shown below, will result in the following:

1) Activate when "Terminate" is received via the Iridium SBD modem, no other trigger conditions

2) Play a B5 note twice of duration one second, separated by quarter second delays

3) Send the **!iCT** (start terminate sequence) to the **!cutr1** HAB Module

4) Pause for 1 seconds

5) Activate the burn-wire attached to Cutter #0 at 3 watts for 5 seconds

6) Pause until the super-caps recharge to 5 volts

7) Play a B5 note twice of duration one second, separated by quarter second delays

8) Pause for 1 seconds

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9) Activate the burn-wire attached to Cutter #1 at 3 watts for 5 seconds

10) Command finishes, can be called again via another Iridium SBD terminate command

```
Command: Terminate
{
  Actions:
  {
    PlayTone: 1047, 0.25, 0.25, 2
    HAB: !cutr1, CT=Y
    Pause: 1.00
    CutLine: 0, 1, 3.0, 5.00, false
    CutterRecharge: 5.00
    PlayTone: 1047, 0.25, 0.25, 2
    Pause: 1.00
    CutLine: 1, 1, 3.0, 5.00, false
  }
}
```

Conditions

This is a list of conditions that must be met for the command to be acted upon. Activate options include:

Arm → Conditions that must be met before the Trigger conditions are compared. Can permit a Command to be activated multiple times instead of the normal single activation. Not required.

Trigger → Conditions that must be met before the actions can be executed.

Disarm → Conditions that disable the command. Not required.

Example: The following example causes a triangular geofence boundary to be active, from one minute until ten minutes after GPS fix acquisition.

```
Conditions:
{
  Arm:
  {
    Compare: Timestamp.MET = 60
  }
  Trigger:
  {
        GeoFence:
        {
          Remain: inside
          Altitude: -500, 2233
          Waypoint: -70.636642, 41.585285
          Waypoint: -70.624188, 41.579674
          Waypoint: -70.625283, 41.589149
        }
  }
  Disarm:
  {
    Compare: Timestamp.MET >= 600
  }
}
```

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Actions

This section holds the commands that the *HAB Pilot* will execute when the *Conditions* are satisfied. The commands are executed sequentially.

Options include:

- CutLine → Activates a cutter output. Requires the CutterControl subsystem to be enabled in the Configuration Section. The five arguments:

  ○ Cutter number, 0 to 3

  ○ Cutter Condition: only activate if the selected cutter passes its continuity test

  ○ Power level, 0.1 to 5.0 watts

  ○ Duration, 0.1 to 32,000 seconds

  ○ Remove from continuity test after activation, true or false

- PlayTone → Causes an audible tone to be played. The *Command's Action* execution will pause while the tone is played. The arguments:

  ○ Frequency, in Hz

  ○ Duration on in seconds

  ○ Duration off in seconds

  ○ Number of iterations through the on/off cycle

- Pause → Causes the *Action* execution to be paused

  ○ Argument: Seconds to delay

- CutterRecharge → Causes the *Action* execution to be paused until the super-cap can recharge to a specified voltage

  ○ Argument: Target super-cap charge level, in volts, to delay until reached

  ○ Range: 0 to 5.1 volts

- HAB → Send a specific command to one or more HAB Modules

  ○ HAB Module(s) name as specified in the Flight.cfg settings
    '*' name wildcard that can be used to send the command to multiple HAB Modules

  ○ HAB Module command, see that HAB Module's User Guide for possible commands

The following is a list of possible logical conditions for Arm, Trigger, and Disarm:

Compare:

This command compares an operational value against a preset value using "<", ">", "=", "<=", ">=". Some possible operational values:

- Timestamp.MET
- System.BoardTemperature
- System.BatteryVoltage
- System.CapVoltage
- System.SystemStatus
- AccMag.AccX/Y/Z
- AccMag.AccAgg
- AccMag.MagX/Y/Z
- HABModule.Batt_dV
- HABModule.Temp_C
- HABModule.Status

- Position.Longitude
- Position.Latitude
- Position.Altitude
- Position.Heading
- Position.GroundSpeed
- Position.VerticalSpeed
- Pressure.Pressure
- Pressure.PressureRate
- Pressure.Humidity

GeoFence:

This condition compares the HAB Pilot's current position against a polygon geofence.

```
GeoFence:
{
  Remain: inside
  Altitude: -500, 2233
  Waypoint: -70.636642, 41.585285
  Waypoint: -70.624188, 41.579674
  Waypoint: -70.625283, 41.589149
  Waypoint: -70.615079, 41.586535
  Waypoint: -70.613184, 41.591485
  Waypoint: -70.629393, 41.596487
  Waypoint: -70.638358, 41.595474
}
```

Arguments include:

- **Remain** → "inside" triggers if the *HAB Pilot* goes outside of the geofence region, while "outside" will trigger if the *HAB Pilot* enters into the geofence region.

- **Altitude** → Minimum and maximum altitudes permitted over the entire geofence.

- **Waypoint** → Each GeoFence needs at least three and not more than 128 waypoints.

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4 Log Files

All SD-card data files are buffered at 2 Hz but only written every ten seconds.

The Flight.CSV Data File

Data

- DateTime   GPS date in YYYY/MM/DD HH:MM:SS format

- MET   Internal second timer, starts counting from 0 at power-on

- Status   A bit-mapped data flag

  - Bit-0   Heater Flag, the battery heater is active

  - Bit-1   Iridium power-save mode

  - Bit-2   GPS Power Save Mode active

- LoCFS

- CutC   Cutter continuity bit-mapped flag (updated every 60 seconds)

  - Bit-0   Cutter #0:   0=Good continuity, 1=No Continuity

  - Bit-1   Cutter #1:   0=Good continuity, 1=No Continuity

  - Bit-2   Cutter #2:   0=Good continuity, 1=No Continuity

  - Bit-3   Cutter #3:   0=Good continuity, 1=No Continuity

- Measurements

  - IntT   The Pilot's internal board temperature, in °C

  - BatV   The Pilot's battery voltage

  - CapV   The super-cap voltage

  - Pressure   Atmospheric pressure, in hPa (millibar)

  - PressureRate Pressure Rate of change, in Pa per second

  - Humidity   Ambient humidity, in percent

  - NumSat   Number of GPS Satellites currently used by the GPS module

  - Lon /Lat   GPS longitude in degree decimal

  - Alt   GPS altitude in meters above Ellipsoid

  - GndS   GPS ground speed in m/s

  - VerS   GPS vertical rate in m/s

  - HDG   GPS heading in degrees

  - AccX/Y/Z   Accelerometer readings in indicated axis, in g's

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- ○ MaxAcc   Max Aggregate Acceleration of all 3 axis, in g's, since last report

- ○ MagX/Y/Z   Magnetometer readings in indicated axis, in degrees

Notes:

- Unless otherwise noted, each data value is updated for every entry.

- Blue text indicates data logged <u>only</u> in ASCII format

The Flight.KML Data File

This file allows rapid plotting of the flight path in applications such as Google Earth.

Note: it not time-stamped. Please use the values from the Flight.CSV file for data that includes a timestamp

The Flight.LOG File

This file provides a log of the system operations, commands sent and received, as well as any issues encountered and errors generated.

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5 Mission Control Software

Iridium SBD data is parsed and displayed in Loonatec's Mission Control software. This software runs on MacOS, Windows, and Linux. It uses a simple interface to display relevant data and send commands. It automatically creates and updates a CSV data file for later reference and a KML file that can be used as a "Network Link" to provide realtime plotting in Google Earth Pro desktop.

1. A selection of preconfigured commands that can be sent to the HAB Pilot

2. A free-form command that can be sent to the HAB Pilot, normally used to send commands directly to a HAB Module

3. The pyrotechnic squib was activated at this point, which changes the reported cutter continuity indicating that it properly fired

4. A line of data from the HAB Pilot. The !cutr1 HAB Module is currently off in the above example.

   1. The first two characters are a TX/RX counter in HEX. Note how the TX counter keeps going up as the HAB Pilot continues to send commands to it, and the RX counter keeps going down as the expected command acknowledgements are never received.

   2. The next field is the HAB Module's status byte (0 in this example)

   3. Followed by the HAB Module's temperature (0 in this example)

   4. And finally the HAB Module's battery voltage (0.0 in this example)

6 Troubleshooting

Device Will Not Turn On

The *HAB Pilot* should turn on within 3 seconds of the power-on switch being moved. If it doesn't, check the following:

- The power-on button not fully being depressed to actuate the switch

- Check the battery orientation

- Install new batteries. The Energizer L91 batteries should not be stored in hot conditions for extended periods of time (months). In that condition they self-discharge more quickly.

Device Can Not Acquire GPS Fix

The *HAB Pilot* normally acquires GPS fix in less than 5 minutes. If it is not able to acquire a GPS fix within 20 minutes then please check:

- That it has a clear and unobstructed view of most of the sky down to the horizon

- That there are GPS satellites overhead and visible to the Pilot.
  https://in-the-sky.org/satmap_worldmap.php

Device Can Not Transmit the Data Header Message

The *HAB Pilot* normally transmits the Data Header Message in the Power-On Sequence within 5 minutes. If it still hasn't sent the message after 20 minutes then please check:

- That it has a clear and unobstructed view of most of the sky down to the horizon

- That the Iridium SBD antenna is aimed upward (batteries will be down, on the bottom)

- That there are Iridium satellites overhead:
  https://www.groundcontrol.com/Iridium_Coverage_Map.htm

7 Consumables

Batteries

The *HAB Pilot* has been designed to use primary lithium batteries in the 'AA' size. The Lithium/Iron Disulfide (Li/FeS2) chemistry has proven to work well, even at the low temperatures experienced on balloon flights. Possible suppliers of these batteries include:

- Energizer Ultimate Lithium L91 AA Battery

- Varta Ultra Lithium 6106 (FR14505) AA Battery

  - Note: the 6106 is rated at 18% less capacity than the L91 battery (2.9Ah vs 3.5Ah)

While the *HAB Pilot* will operate on standard alkaline batteries, it is strongly recommend against using them due to their poor performance at cold.

External Power

External power can be supplied to the *HAB Pilot* via a 2-pin Molex SL connector. Power requirements are 2 to 5.5 VDC, < 0.5 amps from either additional batteries or a solar panel.

Memory Card

Any SD/SDHD micro-SD card should work with the *HAB Pilot*. We recommend using the SD Memory Card Formatter (https://www.sdcard.org/downloads/formatter/) from the SD Association to format new cards. Using the OS formatting utility (Mac OSX or Windows) can cause problems.

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8 Safety Precautions and Recommendations

Regulatory

Always adhere to the regulations governing high-altitude ballooning applicable in the country of operation. In the United States, high-altitude balloon flights are governed by "FAA Part 101".

Always adhere to the regulations for high explosives if pyrotechnic squibs are being used. Some countries restrict ownership, transportation, and use of these devices.

Touch Hazard

Burn-wires are fragile and produce high temperatures when activated. Never press-down on and try to avoid touching the burn-wires.

Falling Payload Hazard

Always clear the launch area prior to launch. While unlikely, balloon or line failure after release may result in a falling payload impacting the ground before the parachute fully deploys.

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