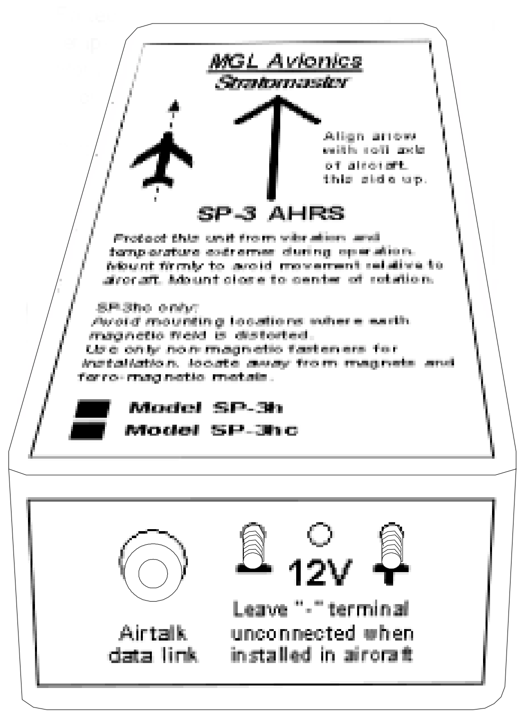
# SP-3 attitude and heading reference system




Preliminary OEM system documentation
Document date 25/6/2004

## General

This document describes the SP-3 sensor package in its two available build versions.
This document is aimed at OEM users who may want to use the SP-3 sensor package in their own products and applications. It is also aimed at the casual user of SP-3 based products who would like to learn more about the SP-3 and how it works.

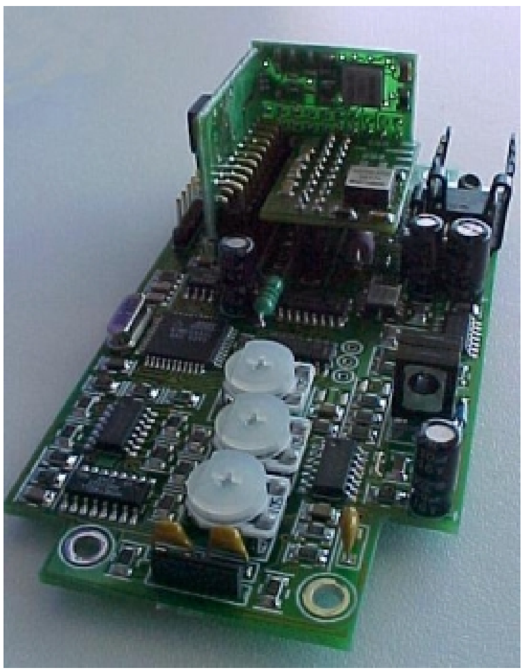


Photo of the SP-3hc electronics assembly.


Photo of the SP-3 unit installed in a non-magnetic IP-65 class housing, showing data connector and power supply terminals.

### *SP-3hc*

This version includes three MEMS gyros, a three axis accelerometer and a three axis magnetometer.
Generally, this package is used to obtain attitude and heading information.
The SP-3hc can be described as a AHRS system consisting of IMU and magnetic heading reference.

This version supports two attitude determination modes: IMU mode and “Mattitude” mode. Mattitude is a system that uses three dimensional earth magnetic field measurements to determine attitude.

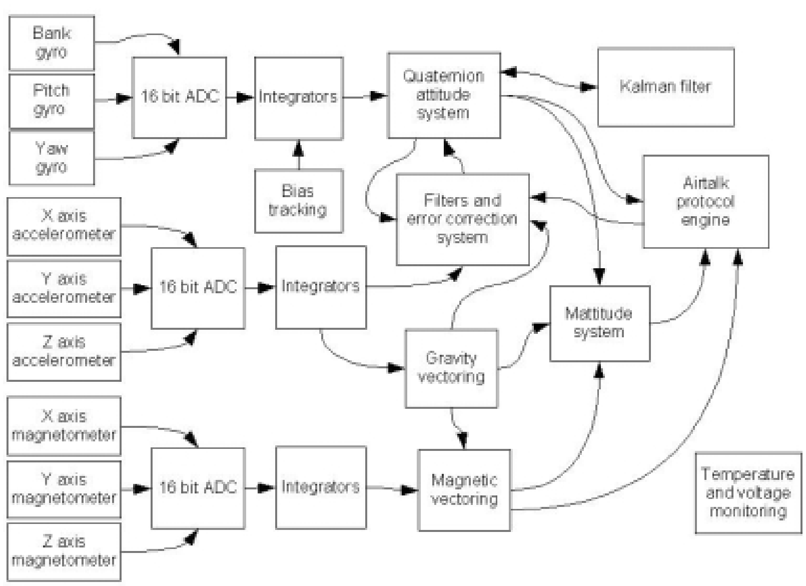
## *SP-3h*

This version includes three MEMS gyros and a three axis accelerometer. This version is intended to give attitude only.
The SP-3h can be described as a ARS system consisting of a IMU.

Both versions are based on similar hardware and software. The SP-3h leaves out all hardware and software components related to the magnetometers.

## *Usage*

The SP-3hc is intended for usage in applications that can provide a clear and undistorted view of the Earth magnetic field. While the magnetometer provides deviation compensation, this should only be used to cancel out minor effects from ajacent hard iron influences.
For applications where it is not possible to obtain a useful magnetic field, the SP-3h should be used, possibly backed up by an SP-1 or SP-2 magnetometer installed in a more suitable location. The “Mattitude” magnetically derived attitude cannot be using external magnetometers due to the high level of intergation with gyro sensor data.




**SP3 Inertial measurement unit and magnetometer**
Principle block diagram

## The IMU

The IMU (inertial measurement unit) is made up from three MEMS gyros mounted orthogonal to each other. These gyros supply rate of turn information around the three major axis of bank, pitch and yaw.
Further to this, three MEMS accelerometers are used to sense linear acceleration along the three major axis.
The signals from these six sensors are integrated and supplied to a quaternion attitude system. Various filters are used to qualify the signals in order to stabilize the quaternion so reliable attitude information can be extracted.
Several filter settings can be chosen by the user to adapt the system to various operating environments.
While the MEMS rate gyros supply rate of turn information, the accelerometers are used to measure the direction and force of gravity and acceleration. This information is used to correct for inevitable gyro drift whenever flight conditions allow for this.
In particular, non-accelerated flight is required from time to time to slew the quaternion attitude representation into the correct orientation. Non-accelerated flight is generally achieved when flying straight and level.
SP-3hc units contain a magnetometer that measures magnetic heading. This information is also used to synchronize the yaw gyro heading. This is the equivalent of the pilot setting a traditional heading gyro to indicate magnetic heading. The SP-3hc does this automatically whenever possible.

## The Magnetometer

This section is not applicable for SP-3h units as no magnetometer is present.

The SP-3hc unit contains a three axis magnetometer of excellent sensitivity and resolution.
The main purpose of the magnetometer is to provide magnetic heading information. The heading information obtained from the three sensors can be compensated for tilt in non-accelerated flight (straight and level). The SP-3hc uses the gravity vector obtained during un-accelerated flight to compensate for tilt.

The magnetic heading system can be operated in one of three user selectable modes:

### *2D, two axis magnetic compass*

This is the simplest method of obtaining magnetic heading. Heading information can be very accurate but is reliant on the SP-3hc unit being absolutely horizontal

to the earths surface. This is required so only the horizontal component of the earth magnetic field is measured.
This mode is not normally used but is included for special applications.

### *3D, three axis tilt compensated magnetic compass*

This method of operation uses signals from all three magnetic sensors. This sensors measure the earth magnetic field in three orthogonal axis, generally called X,Y and Z axis. This information can be used to obtain heading regardless of tilt of the unit, provided it is possible to vector the direction of gravity. This is generally possible whenever the aircraft is in un-accelerated flight (straight and level).
Like the 2D method, heading information will not be accurate during balanced turns due to it being impossible to determine the direction of gravity during this maneuver. However, heading information is still usable during turns as correct indication of “turn direction” and a generally modest error if heading is present. The exact effect is dependent on both actual heading and magnetic inclination (dip angle) at your location.

### *3D, gyro compass slaved to magnetic compass*

As the SP-3hc includes a full three gyro attitude system, it follows that magnetic heading information can be used to synchronize the quaternion heading (yaw axis).
Information transmitted in this mode is that of the extracted quaternion heading which is derived from all three gyros, depending on current angles of bank and pitch.
This heading is synchronized with that of the magnetic compass which operates in 3D tilt compensated mode (see above).
The quaternion will be synchronized if the aircraft is in un-accelerated flight and bank angels are less than 15 degrees.
The equivalent to this system is the traditional cockpit where both a magnetic compass and gyro compass is present. The gyro compass needs to be aligned with the magnetic heading from time to time to correct for gyro drift. This is a manual action that needs to be performed by the pilot. The SP-3hc performs this action automatically whenever possible.

## Attitude determination modes

The SP-3hc unit provides the user with a choice of two different modes to obtain aircraft attitude (bank and pitch).

## *IMU attitude determination*

This mode is the traditional IMU consisting of three gyros and three accelerometers. Gyros provide rate of turn information while the accelerometers are used to vector gravity in order to compensate for gyro drift and also to set the initial orientation of the quaternion.

## *Magnetometer based attitude determination*

This method uses the magnetic vector direction in three dimensions to obtain a relative attitude that can be used as bases for determining attitude relative to the earth surface.
The SP-3hc will automatically obtain the magnetic inclination (dip angle) regardless of its own tilt relative to the earths surface. This measurement needs to be done very accurately. The SP-3 will perform this measurement about once every 10  seconds provided the aircraft is providing a stable enough platform. (benign flight conditions).
The magnetic inclination does not change by a large amount over a large distance, however small local variations of the inclination angle do occur in some locations and it is these variations that the SP-3hc will attempt to track.
The SP-3hc provides a function that allows the user to set the default magnetic inclination. This functions needs to be used at least once and may have to be repeated should the SP-3hc be operated in an area with a different magnetic inclination.
No knowledge of the inclination angle is required by the user during this process as the SP-3hc is capable of measuring this angle.

## *Magnetometer based attitude "Mattitude", how it works*

This method of attitude determination has its origins in satellites where it tends to be used as "course" attitude determination. The SP-3hc however uses different methods. These are described here.

The magnetometers are used to obtain a X,Y,Z vector of the magnetic field relative to the body of the aircraft.
The SP-3 knows at what angle the magnetic field enters the earths surface at the current locale.
Heading is obtained from the "heading gyro", part of the gyro derived attitude quaternion.
Using the three above criteria, the SP-3hc is able to calculate the bank and pitch attitude relative to the earth surface.

## *Why use "Mattitude" ?*

Mattitude has a considerable advantage over traditional gyro/accelerometer systems based on MEMS sensors.
In particular, only heading information is derived from the gyro based quaternion system. This allows the Mattitude system to provide useful attitude information for longer compared to the pure gyro solution as gyro drift has less of an impact.

## *When can “Mattitude” not be used ?*

Mattitude fails if the magnetic properties of your aircraft interfere too much with the earth magnetic field.
In particular iron based objects and magnets can interfere, changing the dip angle and/or magnetic field strength and direction. These effects are usually dependent on your aircrafts magnetic heading and the position of interfering objects in your aircraft.

It is however very easy to verify if you can use Mattitude onboard of your aircraft. This can be done with the aircraft on the ground, away from hangers and reinforced aprons (these contain steel).
After setting the magnetic inclination on your AHRS instrument, turn the aircraft though a full 360 degree circle on the ground. Should the horizon display remain horizontal (showing no unacceptable bank or pitch) during any part of the turn, then you should use “Mattitude” over the more conventional IMU system.

If you find that bank and pitch measurements are unacceptable, try locating a better position for the SP-3hc. You need to find a location where the earth magnetic field passes through your aircraft with little or no distortion.
A small, hand-held compass can be used to scout out a suitable location very easily. Find a location inside your aircraft where the needle points in the same direction as outside your aircraft (move at least 30 ft away from your aircraft). If you have found this location, turn the aircraft by 90 degrees and repeat the procedure. This should give you a suitable location.

You need to be aware that “Mattitude” still uses the IMU for heading (a required item for the calculations). This means that you need to locate a position as close to the center of mass of your aircraft as possible to avoid unnecessary linear accelerations from interfering with the attitude calculations of the IMU.
While installations in the aircraft tail or wings can be considered, these are definitely second choice to a location near the center of mass.

## *How do various locations on earth affect “Mattitude” ?*

Mattitude works best if the magnetic inclination is very steep. Luckily, most locations on earth provide this.
Good locations are:
North America, Europe, South America, Southern Africa, Australia.

Locations near the magnetic horizon can also be used but limitations exist. For example, if you are located close to the magnetic horizon and you are flying exactly along the north-south axis then it is not possible for the magnetic attitude system to measure angle of bank.
However, the system will use other sensors in these cases to bridge the outage.

# The IMU filters

Most IMU systems use a Kalman or extended Kalman filter to combine the various sensor inputs in order to obtain a stabilized attitude.
In order to understand why this is required, lets look at the gyros, the heart of any IMU.

## *Gyros for IMUs*

Until very recently, gyros where very expensive. Unfortunately, they are the only method to measure the rate of rotation around an axis, a fundamental requirement for a strapdown IMU.
IMUs good enough for navigational purposes tended to cost more than $100.000.
Carioles force sensors based on vibrating structures started to give hints of a possible alternative, but they performed extremely badly by comparison with even the most basic mechanical gyro. Nevertheless, they started improving. A breakthough was achieved by the company Analog Devices. On an incredibly small scale, they managed to micro-machine two vibrating structures directly onto a tiny piece of silicon. The two gyros thus formed vibrated in opposing directions, canceling out much of the sensitivity to vibration and acceleration forces that plagued previous attempts.
Still, these gyros are not perfection. They still lag behind a mechanical gyro, not to mention the excellent but unaffordable ring laser gyros (RLG).
Yet, it became possible to consider building a IMU with these devices, considering that during normal maneuvering only short-time accuracy would that plagued previous attempts.
Still, these gyros are not perfection. They still lag behind a mechanical gyro, not to mention the excellent but unaffordable ring laser gyros (RLG).
Yet, it became possible to consider building a IMU with these devices, considering that during normal maneuvering only short-time accuracy would be required. Of course, some means to correct for any accumulated errors was required and this had to be much better than what was required for a high performance system as only small errors would be present with these systems.

## *IMUs for small aircraft*

The SP-3 has been intended for small aircraft, even Ultralights. This presents a problem. Small aircraft have low mass and are greatly affected by turbulence of

any kind. This means that such an aircraft provides a bad platform for the IMU. IMUs want stable platforms. It is very easy to make even a bad IMU perform on a large aircraft such as a 747 as we have a very stable platform. However, take the same IMU and place it in a small aircraft and you will find it will take only seconds until the displayed horizon is unusable.
The IMU in a small aircraft has to contend with a continuous stream of large amounts of data created by linear accelerations due to turbulence, for both high frequency accelerations and rotational information created by vibration and finally, a continuous subjection to G-forces from all directions.
How can one obtain a usuable horizon after thousands of calculations per second keeping in mind that we are getting data from less than perfect sensors ?
Two factors: Time and error detection and correction are the answer.
Time: When the aircraft is in a maneuver that involves acceleration (such as a banked turn), the IMU will determine attitude from integrating the rate of turn information from all three gyros. No other sensors can be considered. The accelerometer does not provide useful information during such maneuvers.
How long can the attitude system provide usable attitude if only imperfect gyros provide data ?
The answer depends on many factors. Gyro linearity, drift and noise being the most obvious determining factors.
External forces such as vibration or extreme temperatures will further degrade accuracy.
It is obvious that bad gyro data will invalidate the calculated attitude in a very short time.
This means that such a system requires periodically an opportunity to correct for errors. On an aircraft this involves un-accelerated flight. Only during un-accelerated flight is it possible to use the accelerometers to obtain a sense of the direction of gravity and thus a reference that can be used to correct for errors of the gyro based attitude system.
Un-accelerated flight can be detected by measuring the total force of acceleration acting on the aircraft. Un-accelerated flight is achieved if this measurement returns a force of 1G (Gravitational force).

Today’s MEMS gyros, properly compensated for drift can provide reasonable performance for a short time provided the overall installation of the IMU avoids factors which would negatively impact performance. Similar installation requirements also affect high end, expensive systems so this should not be taken as a particular requirement for low-end systems.

## *The filters*

The SP-3 contains a host of filters of varying response, carefully chosen for the particular task required.
Two filters can be adjusted by the user. The reason for this is to allow the IMU to be matched as best as possible to the environment it will be operated under.
This is a direct result of the SP-3’s mission to operate on small aircraft providing unstable platforms.

### *The "Bump" filter*

This filter has five settings: Lowest, Low, Medium, High, Highest.
This filter sets the threshold that determines un-accelerated flight. It can be viewed as a limit on the acceleration force acting on the aircraft below which the gyro derived attitude will be corrected by the attitude as derived from the accelerometers.
Typical settings are Low or Medium. Other settings may be useful in some environments.

Effect of too low setting:
System will never or only very seldom have the opportunity to correct errors. Continuous turbulent flight will require a higher setting.
This setting is normally chosen on the mass of your aircraft and how it behaves with turbulence. The more stable your aircraft, the lower a setting you can choose.

Effect of too high setting:
System remains in "accelerometer" mode too long. The most noticeable effect this has is during very slow entries to banks – the displayed horizon may show horizontal even though you have banked or the bank angle is shown too shallow. As the horizon is now wrong, the error will grow quickly as gyro rate information will be misinterpreted.

### *The "Slew" filter*

Like the "Bump" filter, the "Slew" filter also has five settings:
Lowest, Low, Medium, High, Highest.

This filter setting affects the speed at which error corrections take place. Good settings are usually Low, medium or high.

This filter setting interacts somewhat with the Bump setting. Should you find your installation tends to accumulate errors quickly (for example you may have unavoidable vibration affecting the sensors), set the error correction speed higher.
Do not set the error correction speed unnecessarily high as this may degrade your systems ability to correctly detect very slow entries to banks.

### *Finding the right filter values*

Once good filter values are found, they are rarely if ever changed.

Good filter value selection will result in the system remaining in accelerometer mode (indicated on your screen) for most of the time during straight and level flight.
Slow entries into banks are the most critical factor, so try these in calm conditions. Bump factor too high or Slew factor too high (or both too high) may result in bad detection of this maneuver.
Select the Slew factor such that any errors that have accumulated during a full 360 turn at 30 degrees of bank are corrected quickly after you roll out straight and level.

## Using Mattitude after tuning the IMU filter values.

If you have the SP-3hc and have an installation where the magnetic attitude determination system can be used, you still need to ensure that the IMU is well tuned and good filter settings have been chosen.
The Mattitude system uses the IMU for gyro derived heading information and this information needs to be of good quality for a perfect “Mattitude”.

## SP-3 temperature performance

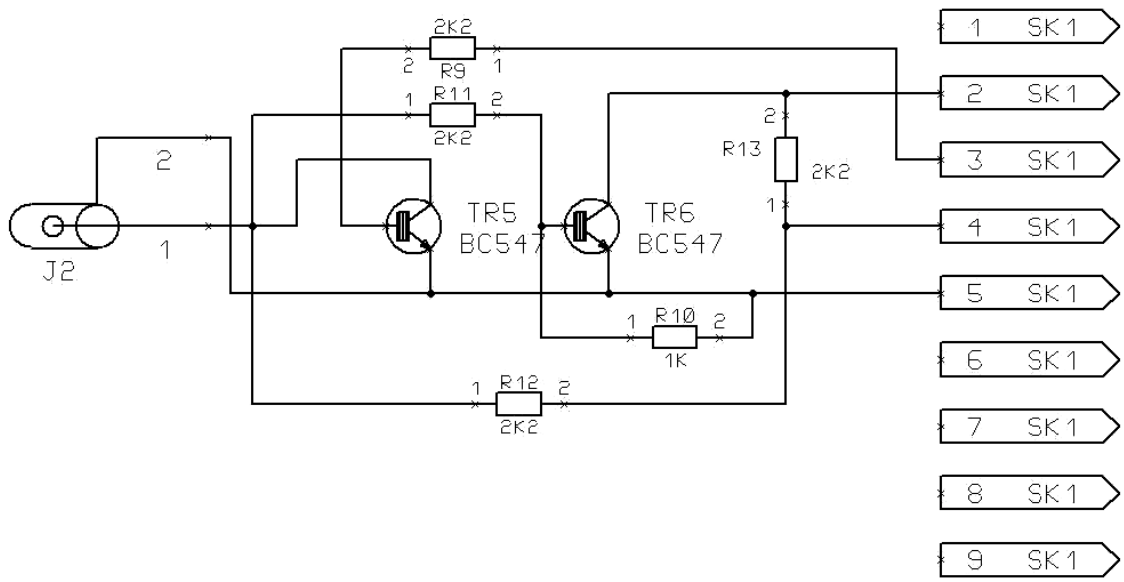
One of the most critical factors in and AHRS system is how it performs when temperatures are low or high. Temperature has a profound influence on all sensors resulting in measurement errors.
The SP-3 provides three measures to combat this effect:
Tracking – long time filters track sensor bias changes.
Compensation – known temperature effects are compensated or canceled.
Temperature regulation – the SP-3 will regulate internal temperature to 40 degrees C, providing a stable environment for all parts of the system. The system will signal when optimum temperature is achieved. However, even outside this temperature the system performs well.

## Communications message formats

The SP-3 unit communicates via the airtalk compatible communications port.
This port consists of a shared, single wire asynchronous link. The link operates with one start bit, eight data bits and one stop bit for a total of ten bits per byte of data transmitted.
Signal levels are <1V for Mark and >3V for Space. Note that this is reversed polarity compared to RS232. This is the native format as used by most serial communication devices.
Data rate is 19200 baud.

A transmitting device generally pulls the line to a low state to signal a “mark” with a weak pullup provided to +5V to drive the “space” or inactive level.

The following circuit diagram shows how to construct a RS-232 to Airtalk link converter. The circuit can be built onto a DB-9 female connector that can plug directly into a serial port of a PC. Note that modem control signals should be initialized so pin 4 is set to a “high” level.




Airtalk messages have the following format:

STX, Destination, Length, message type, data[1], data[2],…,data[length-1], checksum, ETX

The byte $82 is used as STX
The byte $83 is used as ETX

Checksum is the result of all bytes in the message xor’d together with a seed of $A5. The STX,ETX and checksum itself are not included in the checksum.

As the airtalk link is a shared link with several data transmitters possible, it is required to resolve contention issues.
The basic rules for the link are simple:

a) Do not send a message if another message transmission is in progress.
b) Verify the received message for validity using the checksum. Reject any messages where the checksum does not match.

The SP-3 occupies two airtalk addresses as follows:

| | |
|---|---|
| $E4 | Magnetometer |
| $E6 | IMU |

Messages intended for the magnetometer should be addressed to device $E4 while messages intended for the IMU need to be addressed to $E6.
This is a historical convention as early versions of the SP-3 consisted of two independent systems.

Note: Message formats listed here are subject to change without notice. They are correct at release time of the SP-3. Future requirements may lead to messages changing or new messages added. Please contact MGL Avionics if you need to know details related to this.

# Messages transmitted by the SP-3 unit.

Data types:

| | |
|---|---|
| byte | 8 bits unsigned integer |
| int | 16 bits signed integer LSB first |
| sint | 8 bits signed integer |
| fps | 16 bit fixed point.<br>MSB: signed 8 bit integer.<br>LSB: fractional part. |
| fpl | 32 bit fixed point. Lower 16 bits is fractional part, upper 16 bits is integer part. |
| fpx | 32 bit fixed point. Lower 24 bits is fractional part, upper 8 bits is integer part. |
| word | 16 bit unsigned integer |
| long | 32 bit signed integer |

## *Attitude message format one*

The SP-3 will transmit the attitude message ten times per second.
This is the default message format that all Stratomaster instruments expect.
This message will be sent unconditionally.

| | | |
|---|---|---|
| $FF | byte | Destination address: All |
| $10 | byte | Message length 16 bytes |
| $55 | byte | Message type |
| $00 | byte | Message subtype: normal attitude message |
| BankAngle | int | Range –179…+180 degrees |
| PitchAngle | int | Range –90…+90 degrees |
| YawAngle | int | Range –179…+180 degrees |
| Slip | sint | Range –50…+50 |
| GF | fps | Range 0…2G (10G on custom models) |
| MISC | byte | Mode bits (see description below) |
| Heading | word | Magnetic or gyro heading 0…359 degrees |

| | | |
|---|---|---|
| MagMode | byte | Description of heading type (see below) |
| Voltage | byte | input voltage of SP-3 (see below) |

## *Attitude message format two*

The SP-3 will transmit the attitude message ten times per second.
This is an alternative message format. In order to receive this message, the message type selection must be sent to the unit. Once selected, the SP-3 will output this message until another message format is selected. The message type selection is stored in permanent memory and will not be lost if power is lost.

The quaternion will be useful if you need to resolve attitude to less than one degree resolution. The quaternion is normalized. In order to obtain attitude, you need to convert the quaternion to Euler angles. Exhaustive literature on the subject exists and thus it will not be discussed in this document.

This message will be sent unconditionally.

| | | |
|---|---|---|
| $FF | byte | Destination address: All |
| $17 | byte | Message length 23 bytes |
| $55 | byte | Message type |
| $01 | byte | Message subtype: quaternion attitude message |
| Angle | fpx | Quaternion element one |
| X | fpx | Quaternion element two |
| Y | fpx | Quaternion element three |
| Z | fpx | Quaternion element four |
| Slip | sint | Range –50…+50 |
| GF | fps | Range 0…2G (10G on custom models) |
| MISC | byte | Mode bits (see description below) |
| Heading | word | Magnetic or gyro heading 0…359 degrees |
| MagMode | byte | Description of heading type (see below) |
| Voltage | byte | input voltage of SP-3 (see below) |

## *Attitude message format three*

This is the attitude message sent if the SP-3 unit is in calibration mode. Selecting this message format automatically enables acceptance of calibration messages. The message rate is 10 messages per second.

| | | |
|---|---|---|
| $FF | byte | Destination address: All |
| 46 | byte | Message length 46 bytes |
| $55 | byte | Message type |
| $02 | byte | Message subtype: calibration attitude message |
| PitchRate | long | actual raw rate of turn around the pitch axis |
| BankRate | long | actual raw rate of turn around the bank axis |

| | | |
|---|---|---|
| YawRate | long | actual raw rate of turn around the yaw axis |
| Temperature | word | temperature as measured on one of the gyros |
| BankNull | word | current bias of bank gyro |
| PitchNull | word | current bias of Pitch gyro |
| YawNull | word | current bias of yaw gyro |
| AcBank | int | bank angle from accelerometer |
| AcPitch | int | pitch angle from accelerometer |
| Bank | int | bank as output |
| Pitch | int | pitch as output |
| Pitchtrack | long | pitch accumulator for calibration |
| Banktrack | long | bank accumulator for calibration |
| Yawtrack | long | yaw accumulator for calibration |
| Gforce | fpl | G-force total |

### *Attitude message format four*

This is the raw data message. This message is useful if you would like to construct your own attitude or navigation system.
This message is sent unconditionaly 40 times per second.

| | | |
|---|---|---|
| $FF | byte | Destination address: All |
| 23 | byte | Message length 23 bytes |
| $55 | byte | Message type |
| $03 | byte | Message subtype: Raw data |
| BankGyro | word | Rate of bank |
| PitchGyro | word | Rate of pitch |
| YawGyro | word | Rate of Yaw |
| X Accel. | int | X axis accelerometer |
| Y Accel. | int | Y axis accelerometer |
| Z Accel. | int | Z axis accelerometer |
| X Mag | int | X axis magnetometer |
| Y Mag | int | Y axis magnetometer |
| Z Mag | int | Z axis magnetometer |
| Temperature | word | Internal temperature |
| Voltage | byte | Supply voltage level |

Gyro information is integrated over a total of 64 samples (Gyro sample rate is approximately 2500 samples/second/Gyro). The value is the 16 bit result as obtained by integrating the 64 samples from the 16 bit ADC. This value includes the gyro bias (bias is around 32768). No temperature or drift compensation is done on the data, it is Raw data that you can use anyway you like.
Accelerometer information is Raw data as measured directly at the sensor outputs. Data is biased around 32768 + sensor offset. The data is subject to a 8x oversample from a raw data rate of 300 samples/second per sensor.
Magnetometer data is fully compensated field strength information consisting of magnitute and direction (sign of data value). The data is obtained BEFORE deviation and sensor offset compensation has been performed.

Temperature is a word containing the temperature in degrees Kelvin where every 110.1 count is equal to one degree.
The data format for Voltage is described below.

## E2 calibration dump IMU

| | | |
|---|---|---|
| $FF | byte | Destination address: All |
| 56 | byte | Message length 56 bytes |
| $54 | byte | Message type |

this is followed by 55 bytes of calibration data as stored in the E2 memory. This data is relevant only for the IMU. The magnetometer has its own calibration data storage area.
Contact MGL Avionics if you need to know how this data is to be interpreted.

## E2 calibration dump compass

| | | |
|---|---|---|
| $FF | byte | Destination address: All |
| 49 | byte | Message length 49 bytes |
| $62 | byte | Message type |

this is followed by 48 bytes of calibration data as stored in the E2 memory. This data is relevant only for the compass/magnetometer. The IMU has its own calibration data storage area.
Contact MGL Avionics if you need to know how this data is to be interpreted.

## Magnetic inclination

| | | |
|---|---|---|
| $FF | byte | Destination address: All |
| 6 | byte | Message length |
| 57 | byte | General information response |
| 0 | byte | response data type: Inclination |
| INCL | fpl | Inclination |

This message can be requested from SP-3hc units. It returns the last measured magnetic inclination. The value returned is relative to the magnetic south pole. Values are negative from 0 to –180 degrees. 0 degrees is the magnetic south pole, -90 degrees at the magnetic horizon and –180 degrees at the magnetic north pole.

## Raw magnetic sensor data

| | | |
|---|---|---|
| $FF | byte | Destination address: All |
| 13 | byte | Message length |
| 61 | byte | Magnetic data |
| X | long | value of X axis magnetometer |
| Y | long | value of Y axis magnetometer |

| | | |
|---|---|---|
| Z | long | value of Z axis magnetometer |

This message contains raw sensor data obtained from the magetic field sensors. Values are signed long integers.
The values are the differential of the two saturated sensor states that are used to obtain magnetic field strength with magneto resistive sensors.
This data has to be requested. Message structure for this is described further on in this document.

## *Acknowledge*

| | | |
|---|---|---|
| $FF | byte | Destination address: All |
| $02 | byte | Message length 2 bytes |
| $0A | byte | Message type |
| $00 | byte | zero byte |

This is a standard airtalk message. This message is sent by the SP-3 in response to the reception and/or completion of a received command that does not itself result in a response.
The transmitting node will receive this message as acknowledgement that a message sent to the SP-3 has been received. This message is not sent if the received message results in a response.
For example:
If you request E2 calibration data the SP-3 will not send an acknowledge but will send the requested data.

## *Data formats used in SP-3 messages*

MISC

This byte contains bits defined as follows:
Bit 0 - if 0, SP-3 is in accelerometer mode, if 1, SP-3 is in gyro mode.
Bit 1 - if 1, SP-3 is in over range mode (gyro maximum rate exceeded)
Bit 2 - if 1, SP-3 is at operating temperature
Bit 3 - if 0, SP-3 is operating in IMU mode, 1 is SP-3 in Mattitude mode

MAGMODE

This byte reflects the operating mode of the heading output

1 – 2D mode
2 – 3D accelerometer tilt compensated mode
3 – Gyro heading mode slaved to 3D mode

Voltage

Voltage at SP-3 supply input in steps of 0.1 volt. A reading of 255 means 25.5 volts or greater.
The voltage may be measured incorrectly if the unit is operated below minimum voltage of 7.5V DC.

# Messages received by the SP-3 unit.

During normal operation, few, if any messages are sent to the SP-3. Most of these messages are used during device testing and calibration.
Sending a message that affects the units calibration has to be done with great care. Incorrect usage of these messages will render your SP-3 unusable.

## *Set accelerometer X and Y to zero gravity*

This message is only accepted in calibration mode.
This message is sent with the SP-3 aligned perfectly horizontal (verify with a spirit level). This message sets the zero point for X and Y axis. It also sets the 1G point for the Z axis.
This message needs to be repeated after the Z point zero gravity point has been calibrated (with the SP-3 tilted exactly 90 degrees, lying on its side).

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 2 | byte | Message length |
| 53 | byte | Setup IUM items |
| 0 | byte | Function ID |

## *Set temperature sensor offset*

This message is only accepted in calibration mode.
This message is used to calibrate the internal temperature sensor at time of production at the factory. It is not normally used by the users application.

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 3 | byte | Message length |
| 53 | byte | Setup IUM items |
| 1 | byte | Function ID |
| 0/1 | byte | decrease reading=0, increase reading=1 |

## *Set yaw rate calibration factor*

This message is only accepted if the IMU is in calibration mode.
The calibration value is calculated from the integrated gyro output accumulated over a 360 degree rotation around the yaw axis. This value is available in the attitude message type three (YawTrack). The Yawtrack value is set to zero using another message transmitted to the SP-3 at the start of the 360 degree rotation.

The calibration procedure is carried out in both rotational directions (it does not matter which direction is first).

Sample Pascal code to calculate the calibration factor:

```
Var
  Calib: word;
begin
  calib:=1179648000 div abs(YawTrack div 20);
  if YawTrack<0 then Calib:=Calib or $8000;
end;
```

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 4 | byte | Message length |
| 53 | byte | Setup IUM items |
| 3 | byte | Function ID |
| Factor | word | calibration factor |

## *Set bank rate calibration factor*

This message is only accepted if the IMU is in calibration mode.
Equivalent to yaw rate calibration, please view description on procedure in that messages description.

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 4 | byte | Message length |
| 53 | byte | Setup IUM items |
| 4 | byte | Function ID |
| Factor | word | calibration factor |

## *Set pitch rate calibration factor*

This message is only accepted if the IMU is in calibration mode.
Equivalent to yaw rate calibration, please view description on procedure in that messages description.

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 4 | byte | Message length |
| 53 | byte | Setup IUM items |
| 5 | byte | Function ID |
| Factor | word | calibration factor |

## *Set message output format*

Use this message to select one of three output message formats.
Please note that message format 3 is not permanent. It will revert to either 1,2 or 4 (as selected previously) if power is removed.
Setting the SP-3 to transmit message format 3 will enter calibration mode.

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 4 | byte | Message length |
| 53 | byte | Setup IUM items |
| 6 | byte | Function ID |
| msg | byte | desired output message format, values 1,2,3 or 4 |
| msg | byte | duplicate of the above for security reasons |

## *Set rate output integrator to zero*

This message is used as part of the gyro rate of turn rate calibration.
Sending this message will reset the three rate of turn integrators to zero. This message is sent at the start of a 360 degree rotation. The SP-3 will respond with an acknowledge message.

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 2 | byte | Message length |
| 53 | byte | Setup IUM items |
| 7 | byte | Function ID |

## *Measure and set gyro bias*

This message is only accepted in calibration mode.
Send this message with the SP-3 perfectly stationary and at operating temperature.  The SP-3 will measure the gyro bias which will be used as startup default value.

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 4 | byte | Message length |
| 53 | byte | Setup IUM items |
| 8 | byte | Function ID |
| $55 | byte | The value $55 |
| $AA | byte | The value $AA |

## *Set bump factor*

This message passes a 16 bit word that sets the bump factor.
Values representing the standard instrument selections:

| | |
|---|---|
| Lowest: | 50 |
| Low: | 100 |
| Medium: | 200 |

| | |
|---|---|
| High: | 300 |
| Highest: | 500 |

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 4 | byte | Message length |
| 53 | byte | Setup IUM items |
| 9 | byte | Function ID |
| BF | word | Bump factor |

## *Send IMU E2 data*

This message results in the SP-3 transmitting the current E2 memory block containing calibration data.
This function is normally used at factory level to verify that all calibration settings are within acceptable tolerances (this confirms correct sensor operation).

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 2 | byte | Message length |
| 53 | byte | Setup IUM items |
| 10 | byte | Function ID |

## *Set gyro temperature compensation factors*

This message is only accepted in calibration mode.
Our recommendation is: DO NOT USE THIS MESSAGE.
This message is used in a controlled temperature environment to set calibration factors compensating for temperature related variances of the gyros.
Usage of this function is intended only at factory level.

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 2 | byte | Message length |
| 53 | byte | Setup IUM items |
| 11 | byte | Function ID |

## *Set horizon to gravity vector*

Send this message to set the quaternion to the gravity vector (and magnetic heading in case of the SP-3hc).
This message is usually triggered by pilot action to quickly restore the horizon display after it has been invalidated by some reason (for example maximum rate of turn exceeded).
The SP-3 will respond with an acknowledge message.

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 2 | byte | Message length |

| | | |
|---|---|---|
| 53 | byte | Setup IUM items |
| 12 | byte | Function ID |

### Set X axis accelerometer 1G point

This message will set the X axis 1G point. For this the SP-3 needs to be tilted onto its side exactly 90 degrees from the horizontal (verify this with a spirit level). This function sets the X axis 1G point and the Z axis zero gravity point.
The SP-3 will respond with an acknowledge message.

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 2 | byte | Message length |
| 53 | byte | Setup IUM items |
| 13 | byte | Function ID |

### Set Y axis accelerometer 1G point

This message will set the Y axis 1G point. For this the SP-3 needs to be pitched onto its end exactly 90 degrees from the horizontal (verify this with a spirit level). This function sets the Y axis 1G point.
The SP-3 will respond with an acknowledge message.

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 2 | byte | Message length |
| 53 | byte | Setup IUM items |
| 14 | byte | Function ID |

### Measure and set magnetic inclination

This function is not available in the SP-3h.
This function measures the inclination angle of the earth magnetic field and stores it as default reference for the “Mattiude” attitude reference system. This function is used by the pilot whenever the SP-3 is in a new area with a different magnetic inclination.
The SP-3 does not have to be horizontal for this measurement but should be within +/-15 degrees of the horizontal for best results. The SP-3 must be stationary for this measurement to be accurate.

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 2 | byte | Message length |
| 53 | byte | Setup IUM items |
| 15 | byte | Function ID |

### *Set slew factor*

This message passes a 16 bit word that sets the slew factor.
Values representing the standard instrument selections:

| | |
|---|---|
| Lowest: | 50 |
| Low: | 100 |
| Medium: | 200 |
| High: | 300 |
| Highest: | 500 |

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 4 | byte | Message length |
| 53 | byte | Setup IUM items |
| 16 | byte | Function ID |
| BF | word | Slew factor |

### *Set IMU mode*

This message is not available on the SP-3h.
This message passes a byte value of 0 or 1.
0: SP-3hc to operate in IMU mode.
1: SP-3hc to operate in “Mattitude” mode.

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 3 | byte | Message length |
| 53 | byte | Setup IUM items |
| 17 | byte | Function ID |
| Mode | byte | Mode |

### *Send magnetic inclination angle*

This message is available on the SP-3hc only.
This message requests the SP-3hc to send the angle of magnetic inclination as measured.

| | | |
|---|---|---|
| $E6 | byte | Destination address: IMU |
| 2 | byte | Message length |
| 53 | byte | Setup IUM items |
| 18 | byte | Function ID |

### *Set deviation compensation to factory calibration*

This message clears any user deviation compensation and resets back to the original compensation status as calibrated at the factory.

Factory calibration is done in an area of known magnetic field resulting in a deviation neutral setting of the calibration.
As a side effect of the calibration, sensor offsets are also measured and eliminated.

| | | |
|---|---|---|
| $E4 | byte | Destination address: Compass |
| 2 | byte | Message length |
| 52 | byte | Setup compass items |
| 1 | byte | Function ID |

### *Enter deviation compensation mode*

After this message is received, the compass is set to deviation compensation mode. Deviation data messages are output during this mode approximately four times per second.
During deviation compensation the aircraft is turned on the ground through one or more 360 degree turns in an area with little or no external magnetic deviation (such as created by hangers or reinforced concrete aprons).
Deviation compensation can be canceled or ended with the relevant data collected stored for future use.

| | | |
|---|---|---|
| $E4 | byte | Destination address: Compass |
| 2 | byte | Message length |
| 52 | byte | Setup compass items |
| 2 | byte | Function ID |

### *End deviation compensation mode*

After this message is received, deviation compensation mode is ended. All data collected is processed and the result is the bases for future deviation compensation.

| | | |
|---|---|---|
| $E4 | byte | Destination address: Compass |
| 2 | byte | Message length |
| 52 | byte | Setup compass items |
| 3 | byte | Function ID |

### *Cancel deviation compensation mode*

After this message is received, deviation compensation mode is ended. All data collected is discarded, no change to existing deviation compensation data is performed.

| | | |
|---|---|---|
| $E4 | byte | Destination address: Compass |

| | | |
|---|---|---|
| 2 | byte | Message length |
| 52 | byte | Setup compass items |
| 4 | byte | Function ID |

### *End deviation compensation mode and store as factory default*

After this message is received, deviation compensation mode is ended. All data collected is processed and the result is the bases for future deviation compensation. The data is also stored as factory default.
Please note that using this message will invalidate the factory default calibration, it will be lost with no possibility to retrieve it.

| | | |
|---|---|---|
| $E4 | byte | Destination address: Compass |
| 2 | byte | Message length |
| 52 | byte | Setup compass items |
| 5 | byte | Function ID |

### *Set absolute north*

This message is used to set absolute north alignment after factory deviation compensation has been performed.
In effect this function compensates for possible, small misalignment of the X/Y axis magnetometer chip.
This function can be used to set the heading to 0 degrees magnetic if a small heading error is present. The function will only allow corrections of a few degrees maximum.
The process would be to point the SP-3 exactly to magnetic north (verify that this is actually the case) and then send this message to cause the heading output to read zero degrees.

| | | |
|---|---|---|
| $E4 | byte | Destination address: Compass |
| 2 | byte | Message length |
| 52 | byte | Setup compass items |
| 6 | byte | Function ID |

### *Set Z axis offset*

This calibration function enters the Z axis offset compensation mode.
The method used is to align the SP-3 exactly in the magnetic north-south axis and then to slowly tumble it 360 degrees around the pitch axis. The object being to expose the Z axis sensor exactly in both positive and negative directions to the maximum field strength of the earth magnetic field at your location.
The SP-3 will use this information to calculate the sensor offset.

Please note that there is also a similar message to set the factory default of this offset.

| | | |
|---|---|---|
| $E4 | byte | Destination address: Compass |
| 2 | byte | Message length |
| 52 | byte | Setup compass items |
| 7 | byte | Function ID |

### *Cancel Z axis offset*

After this message is received, Z axis offset measurement is canceled. No setup data is changed.

| | | |
|---|---|---|
| $E4 | byte | Destination address: Compass |
| 2 | byte | Message length |
| 52 | byte | Setup compass items |
| 9 | byte | Function ID |

### *End Z axis offset*

After this message is received, Z axis offset measurement is ended and data collected is used to calculate the sensor offset. This data is stored for future reference.

| | | |
|---|---|---|
| $E4 | byte | Destination address: Compass |
| 2 | byte | Message length |
| 52 | byte | Setup compass items |
| 8 | byte | Function ID |

### *Set compass operation mode*

This message selects one of three compass modes of operation:

1 – 2D mode, two axis magnetic compass
2 – 3D mode, three axis accelerometer tilt compensated compass
3 – 3D mode, gyro compass slaved to a mode 2 magnetic compass

| | | |
|---|---|---|
| $E4 | byte | Destination address: Compass |
| 3 | byte | Message length |
| 52 | byte | Setup compass items |
| 10 | byte | Function ID |
| Mode | byte | Mode value, 1, 2, 3 |

### *Set Z axis gain*

This message sets the Z axis sensor gain. The object is to set the sensor gain so the output equals that of the X/Y sensor. Gain change values are transmitted as a signed byte. Typical values sent are –1,+1, –10,+10, -50,+50.
Neutral gain has a value of 1000.
The procedure to follow is to set the SP-3 on a magnetic heading of exactly 45 with the SP-3 horizontal with the SP-3 operating in mode 2 (tilt compensated compass).
Then, without changing the heading, bank the SP-3 by 45 degrees.
Should the transmitted heading now deviate from 45 degrees, send gain change values until the heading is correct.
This procedure should be carried out using a suitable, nonmagnetic jig as it is difficult to bank the unit by hand and keep the heading accurate.
Please note that there is also a similar message to set the factory default of the gain.

| | | |
|---|---|---|
| $E4 | byte | Destination address: Compass |
| 3 | byte | Message length |
| 52 | byte | Setup compass items |
| 11 | byte | Function ID |
| Gain | byte | Signed byte gain change factor |

### *Send raw compass sensor data*

This message will request the SP-3 to send raw sensor data of the three magnetometers. The data is the differential of the two saturation phases used to obtain magnetic field strength with a magneto resistive sensor.

| | | |
|---|---|---|
| $E4 | byte | Destination address: Compass |
| 3 | byte | Message length |
| 52 | byte | Setup compass items |
| 15 | byte | Function ID |
| Gain | byte | Signed byte gain change factor |

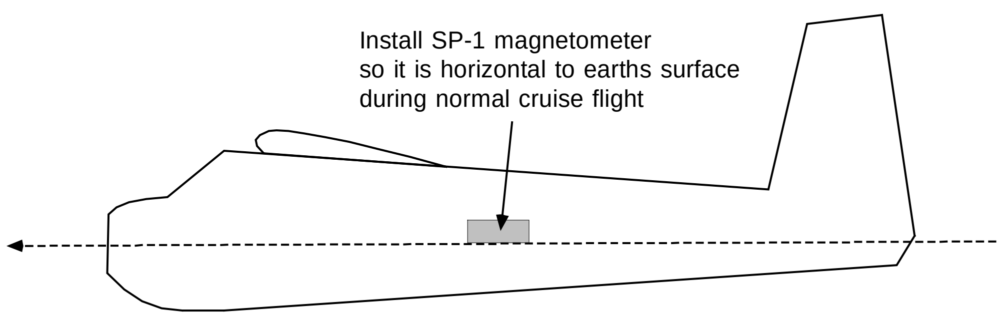
# Installation of the SP-3 sensors

Below are two sections describing installation requirements for the magnetometer (compass) and the IMU.
For the SP-3hc both sections need to be considered. For the SP-3h only the IMU section is of relevance.

## *Installing the compass (SP-3hc)*

The sensor package must be installed such that it is in a horizontal position during normal cruise flight. This is a very important requirement for maximum possible accuracy of the system.
Ensure that you do not have any magnetic materials close to the sensor package.
We recommend ordinary velcro tape for installation as this allows you to easily adjust the orientation of the sensor package. Velcro tape is available in a self-adhesive form but you can glue normal velcro strips onto airframe and sensor housing using contact adhesive.
Should you choose to mount the sensor package using other hardware, ensure that you use only non-magnetic fasteners and materials such as plastic, aluminum, brass or high grade stainless steel. Use a small magnet to test any material if in doubt.
Please be aware that many grades of stainless steel are ferro magnetic. Please test using a magnet before use.

While the compass is normally operated in tilt compensated mode, we recommend that you install system as horizontally as possible .




For maximum accuracy, the tilt compensated compass SP-3hc should be installed so that during all power settings they will not pitch more than +/-15 degrees of the horizontal.

**Important:**
Before installing the SP-3hc, use a small hand-held compass (even a toy compass will be useful) to verify that the location you have chosen does not suffer from large deviation due to influences of your aircraft.

Items that can seriously degrade the performance of your SP-3hc magnetometers:

a) Any ferro magnetic material such as bolts or airframe components.
b) Cables carrying electrical current (the current causes a magnetic field around the cable)
c) Electrical motors. These have powerful magnetic fields.
d) Certain instruments. Some instruments have magnets inside.
e) Relays and solenoids. These are electromagnets.

Should you find any of the above to be problematic, choose another location for the SP-3hc. Alternatively, consider replacing offending materials with better choices. Increase the distance to the offending items, often the effect of offending items will decrease rapidly with distance.

Suggested installation locations for various aircraft:

<u>3 axis aircraft:</u>

Fuselage or wing. Find a location that is as far away as possible from ferro-magnetic materials.

<u>Trikes:</u>

Trike frames operate over a large range of pitch due to power settings. Trikes should ideally fit our SP-2 or SP-3hc tilt compensated compass models.

Perform the deviation compensation procedure as outlined in this manual after you have installed the sensor package.
If you own a tail dragger, you must raise the tail to flight position and rotate though 360 degrees as least once.
For a trike, raise the nosegear to flight position and rotate the trike through 360 degrees. Ensure that you bar position is in the same position it would be during cruise flight if the sensor package is mounted in the wing.
For a three axis tricycle gear aircraft, it may be sufficient to simply taxi the aircraft though 360 degrees if you would fly with the nose wheel not significantly higher than the rear wheels.

Alternate, in-flight deviation compensation procedure:
Place instrument in deviation compensation mode, ensure sensor package is horizontal to Earth’s surface.
Fly a <u>**very shallow**</u> 360 turn keeping any bank or pitch angle to an absolute minimum (less than 5 degrees), during the turn, straighten out periodically during the turn (every 10 to 20 degrees).
Once completed, perform another turn in the same manner but the opposite direction.
When done, leave the deviation compensation mode as described.

Perform this procedure during calm weather conditions to aid you in flying such that no drastic bank or pitch angles will be present during this procedure.

If you plan to use your compass for navigation, please ensure that you perform a normal compass swing after you have completed the installation and deviation compensation. Create a deviation card showing any remaining deviation for the major and minor cardinal points and place this card next to the compass display. This may be a legal requirement for the aircraft category you are using.

## *Installing the IMU (SP-3h and SP-3hc sensor packages)*

Installation of the IMU (inertial measurement unit) is critical to performance of this unit. A bad installation is guaranteed to result in a system that does not function properly.

A low cost IMU operates in exactly the same way that a $100.000 inertial navigation system does. As a result, you need to understand the installation requirements and you have to take great care in providing a suitable installation.

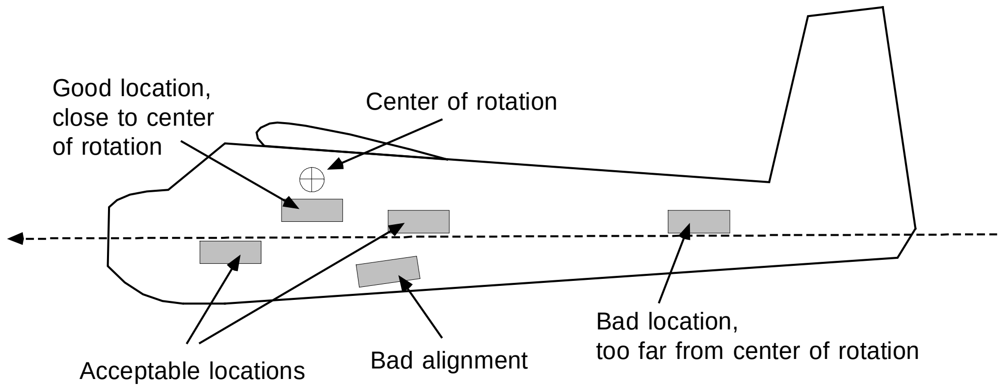
In particular the following have to be taken into account:

a) Location of the IMU must be as close to the center of rotation of your aircraft as possible. Reason: A bad location will introduce accelerations during Yaw, Pitch or Bank. This will interfere with the ability of the system to correctly vector gravity.

b) The IMU must be protected from rapid temperature changes. The IMU is able to operate over a fairly wide temperature range but care must be taken that temperature changes occur gradually. Reason: Rapid temperature changes may exceed the ability of the gyro bias drift tracking to compensate for temperature changes.

c) The IMU must be protected from engine, propeller or rotor vibrations. Reason: vibrations are movements that contain both linear and rotary components. These movements will be detected by the accelerometer as well as gyros and this can severely degrade performance as the system is swamped with false information. In addition, frequency components that are in the same band as the operating frequency of the gyros will lead to immediate, large bias drift that signals false rotation to the electronics of the IMU. The gyros operate at 14Khz. Be aware of harmonics caused by engines at RPM settings of 7000, 3500, 1750 and 875.

d) The IMU must be aligned with the aircraft. Reason: The IMU measures your aircrafts pitch, bank and yaw to calculate the orientation of your aircraft with the horizon. If the IMU is not aligned with your aircraft, then, for example, the Yaw gyro may in fact measure some of the pitch and bank, the same with the other gyros. In this case all calculations will be invalid and the horizon will rapidly show large errors. Your IMU has been measuring signals that are not related to your aircrafts actual movement.

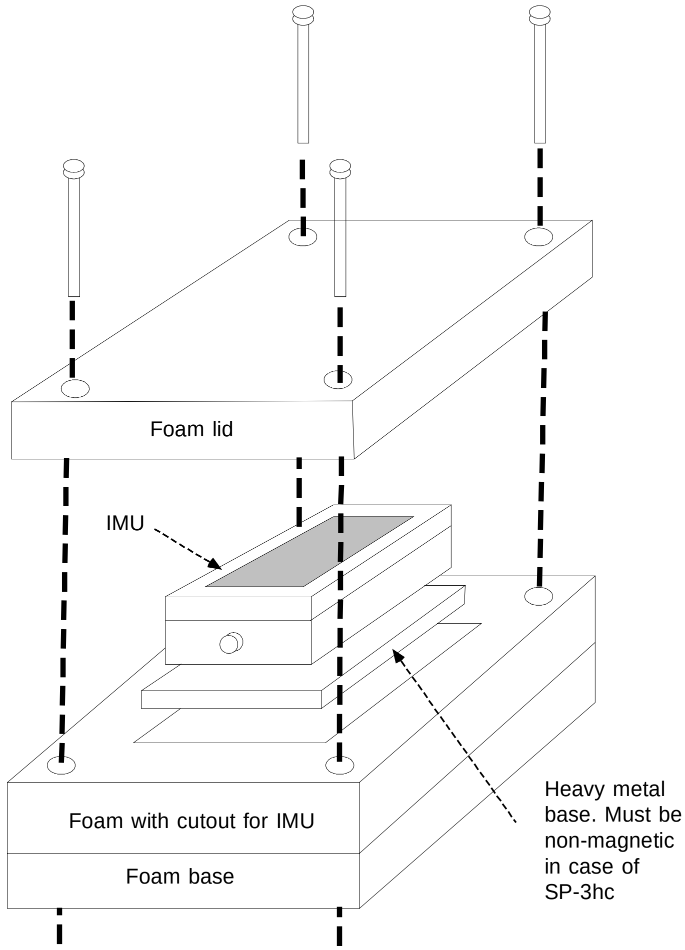



Let us start with the location of the IMU.
The drawing below shows some examples of locations assuming a fairly standard fuselage layout. The IMU should be located as close as possible to the center of rotation which tends to coincide closely with the center of mass of your aircraft.
Often it is not possible to place the IMU exactly at this location. Choose a location as close as you can that is practical.

The drawing also gives an example of a bad alignment. Please try and locate the IMU such that it is aligned with the aircrafts axis of travel at cruise power setting.

Providing a suitable solution to both temperature and vibration isolation is relatively simple. Of course, this is highly individual to your aircraft type and mounting position, so the solution presented here should be seen as a generic suggestion.

## *Suggested anti-vibration and temperature isolation mounting*




A soft foam such as used as fill material for furniture or bedding is ideal and we can use it for both thermal isolation and anti-vibration mount. As the IMU has a very low weight, we need to provide it with a heavy mounting plate to help absorb the vibrations. In case you have the SP-3hc with compass, we suggest to use a plate made from brass, copper or simply cast from lead. In case of the SP-3h you can use steel or iron.
Once closed up, the IMU is well protected against rapid temperature changes as well as vibrations.

Should you choose a solution similar to the above, ensure that the IMU will not be able to move relative to the aircraft. This would result in the IMU measuring different movements to the aircraft itself. The result of this is of course an incorrect horizon display.
A mounting that is too soft can actually worsen the effect low frequency vibrations have on the IMU as the IMU may be exposed to amplified movements triggered by shocks or turbulence.

## *Mounting and using the SP-3, general discussion.*

Mounting locations with only minor vibration will not require an elaborate mounting solution. You may find that mounting the SP-3 directly onto the airframe is quite adequate for your needs. Also, if you do not expose the SP-3 to a high airflow (possibly quite cold), there is little need for temperature isolation.

During development of the SP-3, we deliberatly used a rather bad platform for testing. We used a trike fitted with a two-stroke engine. This aircraft had only

minor vibration protection from the engine. The engine also tends to run at relatively high RPM, making it more likely that engine related vibration will influence the gyros.
The trike is probably one of the worst possible platforms for any IMU. If mounted on the undercarriage for example, movements are measured that have nothing to do with the path of the aircraft though the air.
Further to this, the very light weight and low wing loading factor makes the trike very subseptible to turbulence of any kind. Even in moderate conditions, barely noticed in a larger aircraft, the trike will experience significant accelerations in all directions. This adds a further significant burden to the IMUs processing.
This elliminates the possibility of the IMU compensating for measurement errors by modeling the way a normal aircraft flies.
Much of our development was done with the SP-3 simply taped to an airframe member. The goal was to make it possible for the IMU to perform well enough under these less than ideal conditions to be useful.

This means for the user, that it is probably possible for a less than ideal installation to provide acceptable performance.
However, we would like to stress the point that the better the installation, the better the long term accuracy of the calculated horizon orientation.

For example, a sloppy installation on our trike would allow for us to fly a 20 degree rate one turn for 360 degrees with good accuracy on roll-out. However, prolonged manouvering lasting several minutes, ensuring no opportunety for the IMU to correct for accumulated gyro measurement errors, would start to introduce noticable errors.
Nevertheless, considering that this is not something anybody would do in IMC conditions, you may find this acceptable.

A good installation on an aircraft that provides a stable platform (usualy a larger aircraft of the general aviation category) will result in remarkable performance of the SP-3, approaching (and in many cases ecclipsing) that of much more expensive systems.
Systems that provide a better performance than the SP-3 are nearly exclusively based on RLG devices (ring laser gyros). These are very expensive and somewhat bulky, you will find low grade versions of these devices in commercial aviation of high end general aviation applications. The best of these are nearly exclusively used more military purposes.

We would like to suggest that you start installation by first placing the unit in a perceived suitable location without much effort spent on a mounting arrangement.
Set the Slew factor to “medium”, the prefered setting and also place the Bump factor into “medium” to start of with.
The SP-3 will infact alter your selection of Bump factor depending on the flight dynamics experienced so the Bump factor should be seen as “initial value” that will be applied whenever the unit is switched on.

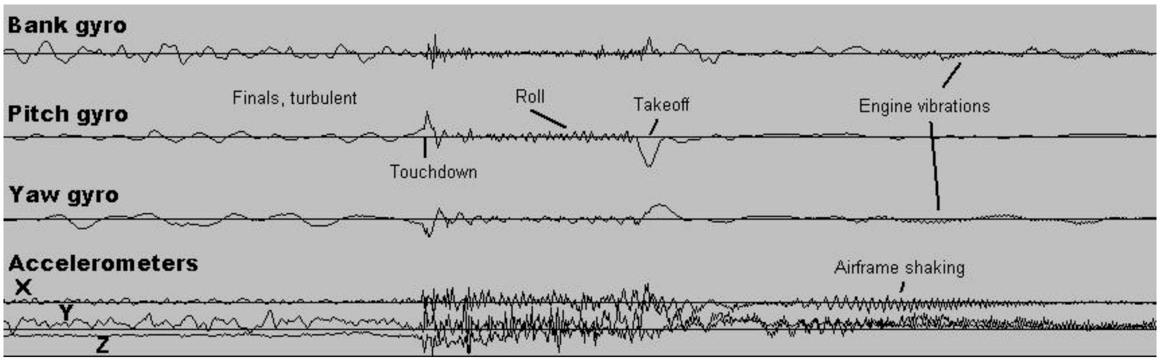
Perform a test flight and monitor the horizon as calculated by the IMU.
When you fly straight and level, the IMU should go into “accelerometer” mode, often indicated by a “A” on your display. As you turn into a bank, the indiction should change to “gyro” mode, often a “G”.
Gyro mode should remain active for as long as you are turning into a bank, yawing or changing pitch. You should also see the unit go into this mode whenever you hit turbulence, even whithout any turns.
Typically, you should aim for about 50% or more time spent by the SP-3 in accelerometer mode during straight and level flight.
Increase the Bump factor if you are spending too much time in Gyro mode, decrease it if you are nearly 100% of the time in accelerometer mode.
Don't adjust the slew factor for these initial trails, “medium” should provide fast enough error correction.

Should you find that the above setting work well on your aircraft, you can attempt to decrease the Bump and Slew factors (try decreased Bump before you decrease the Slew). This can result in improved accuracy in detecting very slow enries into manouvers, such as a very gradual entry into a bank.
Do not set the factors too low, you may find that this could result in the unit having no opportunety to correct for errors if you are flying in turbulent conditions. After a few minutes your indicated horizon may be completely invalid.

Our suggestion is to aim for a medium slew factor and medium or low bump factor. A larger aircraft can generally use the low bump factor for increased accuracy while a small aircraft should use the medium bump factor for increased error correction.
Very small aircraft such as ultralights flying in turbulent conditions may select medium or high bump factors with a higher slew factor for optimized performance, but this needs to be tested and evaluated on a case by case bases.

## *Typical raw data recording*

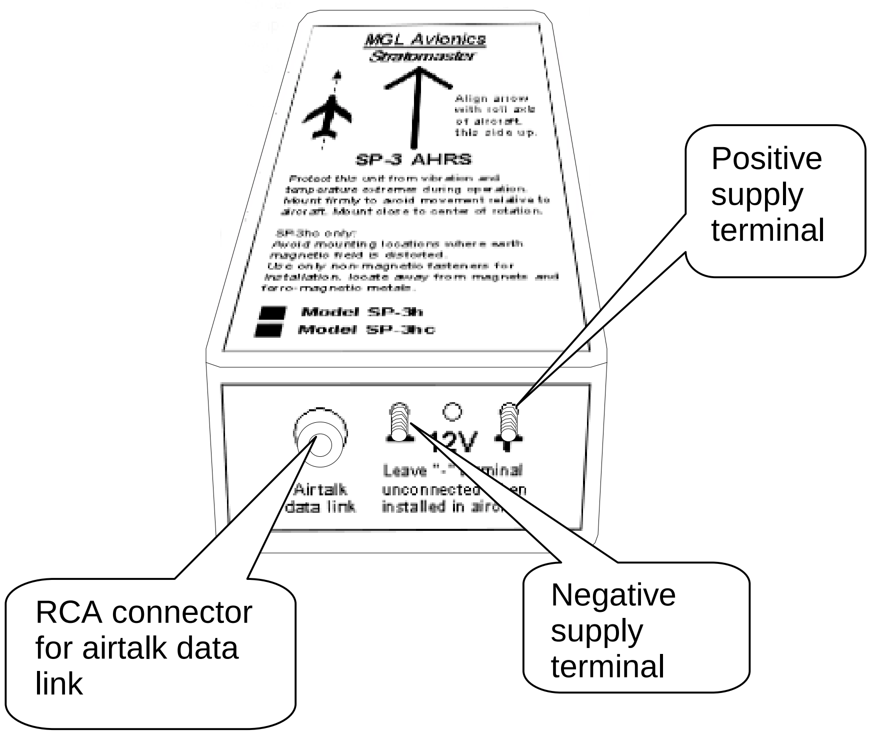
The image below has been obtained from raw data recorded during a touch and go.




The SP-3 was installed on a ultralight aircraft, no provision was made to dampen any engine or airframe vibrations. The SP-3 was simply taped to one of the airframe members. The resulting horizon display was correct thoughout the flight. This serves to give an indication of the abilities of the SP-3 firmware.
The data obtained during this flight was made available by the SP-3 set to mode four data output (Raw data, 40 samples per second).

Interpreting this data, you can observe large inputs from the three gyros during finals. The very light aircraft was exposed to significant turbulence until the point of touchdown. Also interesting are the large pitch accelerations (Y axis) during this phase of flight. Accelerations in the X axis (roll) and Z axis (yaw) where relatively small.
The landing was performed on a concrete runway that is quite smooth. Nevertheless it is apparent that large accelerations are present during the landing roll and subsequent take-off. The aircraft did not have benefit of any form of shock absorbers. The gyros are also outputting rate of turn information during this phase suggesting a relatively rough runway.
The point of take-off is easy to recognise, a large pitch rate of turn signals the exact point of rotation.
Climbout therafter is relatively smooth with only minor bank input from the pilot. Notice however the large vibration amplitudes recorded by the accelerometers. These are typical effects of airframe shaking and the engine running at full power.
Interesting is also the yaw output directly at take-off. The aircraft did in fact yaw as the wheels left the ground due to a cross-wind.

# Electrical connections to the SP-3.




The SP-3 is designed to operate from 8.5V DC to 18V DC. Internal power supply protection includes reverse polarity and overvoltage spikes. Transorb clamping is provided at 33V, with loading above 28V.

It is recommended that a 1A fuse is wired in series with the positive supply terminal.

The negative supply terminal should be left unconnected in all applications where the RCA cable shield will be acting as negative connection. This is typically the case if connected instrument and SP-3 share the same power source.
If the SP-3 is powered from its own private power supply, both positive and negative terminals can be used. Typically, this will be the case if the SP-3 is connected to a PC.

Current consumption of the SP-3 can range from about 80 to 250mA depending on whether the internal heater is turned on or not.
The power supply should be able to supply a constant voltage regardless of the current draw of the SP-3. This is normally the case if a regulated 12V supply is used or if the SP-3 is operated from a charged battery.

## Internal heating system

The SP-3 units have a built in heater. Using this temperature is controlled to be a minimum of 35 degrees Celsius.
The unit will report that it is within calibration if temperatures internal to the unit are above or equal to 30 degrees Celsius.

Heating the internal electronics to a stable temperature provides for the excellent temperature performance of the unit. It ensures stable and predicable signal output of all the sensors.

However, temperature and drift compensation techniques provide good performance even if the calibration temperature is not reached.

Basic installation requirements are:

a) Your power supply must remain stable and with voltage range when the heater is switched on or off.
b) The unit should not be exposed to a high flow of air as this will remove heat from the unit. If the flow of air is very cold, this may prevent the unit from reaching calibration temperature.

# Technical specifications SP-3

Specifications published in this section are “typical”. Individual variations may result in some of these specifications to be better or worse.

Power supply

Input voltage range: 9V to 18V DC regulated preferred for maximum performance. 12V is suggested operating voltage.
Current consumption:
Heater off: 80mA
Heater on: 150-350mA depending on input voltage.
Internal, maintained temperature: 35 degrees C.

Sensor technology:
Gyros: MEMS
Accelerometers: MEMS
Magnetometers: Magnetoresistive
Alignment error total: <1 degree.

Gyro specifications:
Maximum rate of turn around any axis: 170 degrees/second typical.
Bandwidth: 10Hz
Drift short term: <1 degree/Minute. Condition: Error correction off, temperature stable, no movement.
Drift long term <15 degrees/30 Minutes, same conditions as above.
Random noise performance: <0.1 degrees/Second typical.
Drift specifications are obtained using built in bias tracking code, this data can be verified by the user if optional Windows based interface program is used.
Nonlinearity: better than 1% FS, best fit.

Accelerometer specifications:
+/- 2G, any axis.
Temperature drift: <0.02 G/degree C.
Linearity: Better than 1% FS, best fit.

Magnetometer specifications:
Maximum field strength: 3 x Earth magnetic field strength (amplifiers will saturate if this level is exceeded).
Nonlinearity: Better than 1% FS best fit.
Accuracy of compass heading achievable, no deviation present: <1 degree.

Analog to digital conversion:
16 bit, all signals.
Gyro raw sample rate: ~2500/second (each gyro).
Gyro oversample rate: 64.

Accelerometer raw sample rate: ~300/second (each axis).
Accelerometer oversample rate: 8.

Magnetometer raw sample rate: ~300/second (each axis).
Magnetometer oversample rate: 8.

Attitude calculations:
Quaternion system, Q8.24 fixed point, normalized.
No attitude angle restrictions in any axis.
Quaternion update rate: 40/Second.
Euler angle extraction rate: 10/Second.

Compass heading calculations:
4 per second.

Latency, normal output message:
50 mS average.

Latency, raw data output message:
12 mS average.

## Applications

The SP-3h and SP3hc models are intended for the following applications:

Camera stabilization
Antenna stabilization
Attitude and heading reference systems
Short term autonomous navigation
Dead reckoning reference systems
UAV applications (autonomous aerial vehicle).
Autopilot applications.
Almost anything that requires knowledge of attitude…

## Customization

The SP-3 units are designed to fulfill the need of AHRS applications in smaller aircraft that do not provide a stable platform, preventing the use of many ordinary systems. In addition, the SP-3 is designed to be the world's lowest cost solution. These two diametrically opposed requirements require very special and clever firmware to make it work.
This usually means that the SP-3 works exceedingly well in more ideal circumstances. Nevertheless you may have an application that requires changes to the performance, perhaps higher rate of turn etc.
Talk to us at MGL Avionics. We are there to help. If we can do it, we will.