MGL Avionics
SP-6 Magnetometer
SP-7 AHRS

User and installation manual

Document Date: 25/05/2011

About this document

This document describes installation and usage for the SP-6 magnetometer (electronic compass) and SP-7 AHRS (Attitude Heading Reference System) for connection to MGL Avionics flight instrumentation systems.

Connectivity

The SP-6 and SP-7 units are designed to be connected to the AV-1 Infinity, AV-2 Velocity, XTreme, Enigma, Voyager, Odyssey and iEFIS instruments.

The SP-6 and SP-7 units may be used with systems designed by third parties. Please consult relevant documentation of your third party system.

Interface

The SP-6 and SP-7 units make use of the MGL Avionics propriety Airtalk link which is based on ordinary RCA audio or video cables for ease of installation.

The SP-6 and SP-7 units can also be interfaced using a two wire CAN interface or RS232. Interface options depend on the installed formware.

Airtalk is a low speed, low EMI (electrical noise) connection intended to be used with MGL Avionics equipment data links containing modest data rates.

Airtalk is a multi master link allowing several items to share a single connection. A full AHRS system is created by joining a SP-6 and a SP-7 using a single Airtalk link.

The SP-6 magnetometer

The SP-6 magnetometer is a three axis, tilt compensated electronic compass system. It outputs magnetic heading information.

In the case of a standalone SP-6, tilt compensation is performed by deriving the attitude of the SP-6 sensor using on-board accelerometers which are used to vector the direction of gravity. The magnetic field is measured using three magnetometers which are mounted perpendicular to each other resulting in three magnetic force vectors.

Using three magnetic force vectors and knowledge of attitude allows calculation of magnetic heading even if the SP-6 is not horizontal.

There are limitations to this method. During turns the accelerometers will give incorrect indications due to centrifugal forces acting on the SP-6. This will result in incorrect heading readouts during the turn. However, compared to an ordinary mechanical compass, the heading is still usable as it tends to show heading changes in the correct manner (even if heading if not 100% correct) and will allow you to fall out of the turn on the intended heading. The moment you are flying straight, the heading is instantly correct. This is in contrast to a normal mechanical compass which tends to over or under swing and may need considerable settling time.

Alternatively, if you have a SP-7 AHRS connected to the same Airtalk bus as the SP-6, the SP-6 will use the attitude data from the SP-7 to calculate the heading.

If your SP-6 is set to gyro mode and horizon data is being received, your SP-6 will use the gyro derived horizon rather than the built in accelerometers for tilt compensation. In this case, heading is

correct even during turns. Be aware that in this mode, should your horizon be incorrect due to exceeding maximum rate of turns or prolonged maneuvering, your heading will also be incorrect.

SP-6 Installation

The most critical decision to make before installing your SP-6 is to decide on a good location inside your aircraft. Special care needs to be taken to prevent exposure of the SP-6 to significant magnetic disturbances – especially in aircraft containing steel (ferrous metal) structures. Such locations are unsuitable.

Aluminum, brass, fibre glass and carbon fibre are examples of materials that will NOT disturb the magnetic field. Ferrous metals and conductors carrying currents will distort the magnetic filed. The disturbance cased by Stainless Steel will depend on the grade of the Stainless Steel used. Although non magnetic in its highest grade form, many grades will be magnetic as they are not pure. Test with a small magnet if unsure. If the magnet sticks, it is a problem.

We recommend that you do a basic survey using a small hand held hiking compass inside your aircraft to help locate strong disturbances. Note that you must orientate your aircraft on several headings and repeat the process to find a good location – doing this on just a single heading is seldom successful.

Your aim is to find a location that will give you a heading error of less than 10º on any heading in normal flight attitude. Only in this case will you be able to use the built in compensation and alignment functions to eliminate the remaining errors properly. If you start with a large error, perhaps 15º or larger, you have little chance of calibrating this error out. Rather find a better location.

In extreme cases, consider locating the SP-6 outside the fuselage, perhaps in a wing tip. The wires running to the SP-6 can be lengthened if required.

When attempting to find a suitable location for your SP-6, be aware of the following:

Avoid any areas that have iron based metals in close or relatively close proximity.

Avoid proximity of instrumentation containing magnets (many electrical "needle" based instruments contain magnets). Some automotive type GPS antennae contain strong magnets. These magnets can often easily be removed.

Avoid proximity to autopilot servo motors, electric fuel pumps and other electric motors.

Avoid proximity to any wiring containing electrical supply currents (the currents will cause a magnetic field to build up around the cable).

Avoid any proximity to ferrous metallic fasteners such as nuts and bolts.

Avoid or a least be mindful of proximity to luggage storage areas (example the "glove box"). If ferrous metallic items like car keys are stored in these areas, the magnetic field will be disturbed depending on the location and orientation of the disturbance source.

Be aware that the Earth magnetic field is very weak and is easily disturbed by any of the above items. If you want to experiment to find out just how easy it can be disturbed, move a screwdriver close to the SP-6 (once it is connected and operating) and observe the effect on your heading. You may be surprised!

The SP-6 will in all cases faithfully show the direction of the magnetic field passing through it, even if this is not the direction of the Earth magnetic field at your location.

The SP-6 is normally connected to a 12V DC power system. Power consumption is modest at less than 50mA. Power supplies must be protected from transient events that raise voltage levels above

35V (these events can be caused by solenoids and starter motors and other electrical gear). Exceeding a voltage of 35V positive or 100V negative will destroy the SP-6.

Mounting the SP-6

Mount the SP-6 in a position that is not affected by ferrous metals (including nuts and bolts). Mount the SP-6 using plastic, brass or aluminum fasteners. As alternative, consider industrial quick release fasteners such as self-adhesive Velcro or similar systems.

Try to mount the SP-6 in such a way that it will be horizontal or close to horizontal during normal cruise flight. The internal tilt compensation is effective to about 60º pitch and bank but additional errors can still be introduced. These however are very negligible if only small amounts of tilt are present.

If the SP-6 is being installed in conjunction with a SP-7, the two sensors MUST be mounted with the same pitch and roll angles. If this is not done, significant heading errors of the SP-6 will result as it will base its calculations on incorrect attitude.

SP-6 deviation compensation

It is normal to have small amounts of deviation in an aircraft compass installation. Deviation is caused by nearby hard or soft iron and other effects.

With a traditional mechanical compass small magnets are placed or rotated in close proximity to the compass to correct for most of the deviation. It is quite possible to do the same with an electronic compass but there is another way. Objects causing deviation tend to modify the strength of the magnetic field in their proximity. This can be used to help compensate for the deviation in many cases.

Consult your display device's manual on how to enter and leave deviation compensation mode.

Warning: Only proceed with deviation compensation if your deviation is relatively small (perhaps a maximum of 10º). Large deviation can seldom be corrected significantly this way – your only option is to either remove the offending source (such as a iron bolt perhaps) or to find a better location for your SP-6.

Deviation compensation consists of entering deviation compensation mode and rotating your aircraft through at least one full 360º turn on the ground. The SP-6 must during this procedure remain horizontal to the Earths surface. If you have a tail dragger, lift the tail while you perform this maneuver.

Once the turn is completed you need to end the deviation compensation procedure. It is also possible to clear any deviation compensation and return the unit to factory calibration.

Note: Be aware that many concrete reinforced aircraft aprons or runways contain significant amounts of iron which may make it impossible to perform any meaningful deviation compensation on these surfaces. Also, do not attempt to calibrate your compass inside a hanger that contains significant amounts of iron based metals as part of the construction.

SP-6 alignment

Your SP-6 includes a second phase method to calibrate directly to the four cardinal headings (North, South, West and East). Consult your display instrument's manual for details on how to use this function.

The procedure requires that you have exact transits to the cardinal headings that you can use as reference. Note that you need magnetic headings. Use a small survey or good hiking compass to find suitable transits.

This calibration is intended to be performed after normal deviation compensation to eliminate remaining deviation or to be used on its own if you only need to correct for very small deviation and the normal procedure does not fully compensate for all errors.

Align your aircraft with the cardinal heading you wish to calibrate and select the heading to calibrate. This method works well if small deviations need to be compensated for (less than 5º errors). The SP-6 will create a smooth interpolation between the four calibration headings. View your display instruments manual on how to do this.

SP-6 general discussion

The SP-6 is based on Honeywell magnetoresistive sensors. These sensors are very sensitive to magnetic fields and are able to measure tiny field variations. However, the sensors also have large undesired error components caused by temperature and aging.

SP-7 AHRS

The SP-7 AHRS is MGL Avionics's seventh generation AHRS system. The core building blocks of the system includes a three axis ST MEMS rate gyroscope, a three axis ST MEMS accelerometer and an ARM Cortex 32-bit microprocessor system.

SP-7 AHRS explained

Before you proceed with the installation of your SP-7, it is wise to study how the SP-7 AHRS works so you can understand how to perform the installation to ensure that the system performs at its best.

While the SP-7 is much cheaper than a traditional AHRS system as installed in military aircraft or airliners, the very same principles of operation are used and the same restrictions and limitations are present. More than with any other system in your aircraft, the performance of the AHRS is dependent on the correct installation of the system.

The SP-7 is a "strapdown AHRS", a term used for a system that is not based on the traditional spinning body gyroscope (vacuum or electric gyro) but rather uses three separate gyroscopic devices to measure rotation rates around each of the three major axis. This is combined with three accelerometers that measure specific force in the same three axis.

How does it work ?

The rate gyroscopes have no way of "knowing" where the Earth surface is in relation to your aircraft. During non-accelerating flight the measurement from the accelerometers can be used to calculate the attitude of the AHRS relative to the earth – but only if your aircraft is not accelerating, decelerating or changing direction of flight. In principle, the accelerometers can give us the information we need if you average them over a long time (much longer than your average maneuver, like a turn, would take). But of course that would give you a very slow result that is all but usable.

Enter the rate gyroscope. Using a sophisticated piece of mathematics, it is possible to work out using turn rates around three axis how the horizon (that we know from the accelerometers) is changing in the short term. Unfortunately, while the gyros are very good at giving a good result following through a few maneuvers, accumulated measurement errors will eventually cause the calculated horizon to drift. The interesting part is that this applies to all strapdown systems - regardless of how expensive the gyros are! It might just take a little longer until the errors become a problem in the case of the more expensive systems.

How does this affect us? The system will work fine if we allow the accelerometers opportunity to

correct any error that has accumulated during a maneuver that relied on only the gyros to calculate the movement of the horizon relative to your aircraft.

In practice, with careful and clever design of the software in your AHRS, your AHRS will work fine for normal flight which would normally consist of mostly straight and level flight inter spaced with relatively short maneuvers (such as turns). During the straight and level parts of the flight, the information from the accelerometers is dominant in determining your attitude while during any maneuver (or turbulence induced rotations) the gyros become dominant.

Should you be flying a continuous maneuver without ever giving the AHRS a chance to re-vector Earth's gravity, your horizon will eventually drift out.

Just how long this takes is dependent on two factors: the quality of the system as a whole (including the rate gyroscopes) AND the quality of your installation.

SP-7 installation

The SP-7 and SP-6 must be rigidly fixed to your airframe (i.e. it must not move relative to your airframe - except for the bit of vibration damping to be provided for the SP-7).

The AHRS must be aligned correctly to your airframe. The horizon picture you are seeing on your display is not that of your aircraft but that of the AHRS.

Any undesired movement must be kept away from the AHRS as this will corrupt the horizon due to additional calculations and hence additional, small errors.

Vibration, such as caused by an engine is poison to an AHRS. Vibration contains many linear and rotational movements at high frequency, many above the maximum rate of rotation that can be measured by the gyros. If your AHRS is exposed to engine vibration it will significantly reduce the performance of your system. Read this part again – it is the single biggest factor that you must understand. Use any means possible to mount the SP-7 such that vibration is minimized as far as possible.

Temperature. Avoid exposing your AHRS to extreme temperatures, both hot and cold. Also avoid rapid temperature changes. The gyros react badly to temperature changes. Your SP-7 contains an internal heating element that will try and maintain a constant internal temperature of about 35º Celsius to assist in this matter.

Location. The ideal location for the AHRS is in the center of rotation of your aircraft. This is seldom possible though. However, try and find a location that is as close as possible to the center of rotation. Any significant distance from the center of rotation (more than say 5ft) will cause the accelerometers to read incorrect information. For example: Consider that you have installed the SP-7 some distance behind the center of rotation. If your aircraft yaws, the X axis accelerometer will think that you are banking due to the centrifugal forces created by the yaw.

Power. Last but not least – make sure your power supply is stable and provides sufficient voltage AT ALL TIMES. Electrical noise on the supply is not a good thing and will degrade performance – the AHRS has to measure extremely small signals to be accurate. A noisy electrical environment does not help.
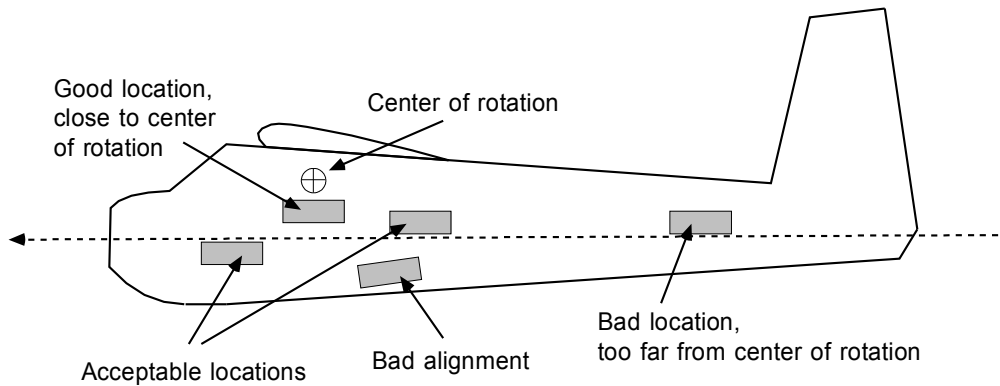
Location and Mounting of the SP-7

SP-7 mounting

The SP-7 can be mounted by means of the four bolt holes in the flanges.

Alternatively, industrial quick release fasteners such as self adhesive Velcro strips can prove to be an easy option.

Should mounting require vibration absorption, a suggested technique would require the SP-7 to be mounted on a heavy base plate (consider lead or other heavy material). This base plate would then be mounted onto a soft rubber sheet of sufficient thickness. In turn the rubber sheet would then be mounted to a suitable surface on the aircraft.

The consistency of the rubber sheet must be chosen such that the SP-7 does not readily move on its own relative to the airframe if exposed to airframe shocks but is flexible enough to prevent vibrations from being transmitted mechanically to the SP-7.

SP-7 operational options

Your SP-7 ships with internal filters set to default states which is likely all you need. These filters have been designed to optimize performance for the average aircraft and installation.

What is a filter? A filter in this context is a software algorithm that takes various factors like time and sensor signals and processes these depending on some criteria. Your SP-7 contains many such filters.

The slew filter

Your SP-7 will use velocity of your aircraft in order to optimize some algorithms in order to be able to better judge some of the sensor data.

Velocity information may be derived from airspeed (true airspeed is required) or from a GPS receiver. Instruments that provide this information to the SP-7 currently include the Stratomaster Ultra HXL, XTreme, Enigma, Voyager, Odyssey as well as all iEFIS systems.

The slew filter is used if external velocity information is not available. In this case the algorithms operate in a reduced velocity compensation mode in very defined situations only. You use the slew filter to effectively tell the AHRS the speed that you will be flying most likely (normally your cruise speed).

EFIS Setting	Speed [mph]
Lowest	50
Lower	70
Medium	100
Higher	150
Highest	200 (or higher)

Select the value that best describes your cruise speed (true airspeed). Consult your display unit's documentation for instructions on how to change this filter setting.

Note: If you are using the SP-7 with an AV-1 or AV-2 unit, you **must** perform this setting. Note that the instrument does not display the current setting, it is a "one-way" operation. You select the desired setting and this is then sent to the SP-7 where it is stored and used.

If you are using an instrument that sends velocity information to the SP-7, you do **not** have to perform this operation.

SP-7 general operation

The SP-7 would normally be switched on with the aircraft stationary. It quickly finds and stabilizes current gyro biases and sets the horizon from the information measured by the accelerometers. This process typically takes less than 15 seconds.

Maximum accuracy is achieved a few minutes after startup if at a relatively cold ambient temperature. Less time is required if you are operating on a warm summer day. The SP-7 contains a built in heater element to speed up heating to operational needs (35º Celsius internal). This heater will operate at less effectiveness if your power supply voltage is low. The heater is intended to operate at full efficiency between 12 and 20V DC.

Should power be cycled in flight, the SP-7 will track the horizon very quickly after start-up if the aircraft is held in non-accelerated (such as straight and level) flight.

The horizon should track well in straight and level flight, even with relatively severe aircraft motion caused by turbulence. The horizon should not show any noticeable error after flying a complete rate one turn (two minutes for 360º). As you turn out straight, the horizon should be instantly correct. If not, check your installation – something is upsetting the SP-7.

SP-7 for blind flight operations (IFR flights)

The SP-7 is not certified for professional level IFR usage.

Should you find yourself in a position where you need to use the SP-7 as reference without any other available option proceed as follows:

Place the aircraft in straight and level flight at a speed that results in best overall stability. Usually this is less than the rated cruise speed and below maneuvering speed.

Check your compass heading if you have an electronic compass such as the SP-6. You will be using the compass heading as backup to the horizon. Check your slip indicator (you should have a slip indicator display derived from the accelerometers in your SP-7). You will be using the slip indicator as backup as well.

Ensure that you are in a stable flight with the ball centered and on the desired heading. Crosscheck your position with GPS. You need to know exactly where you are and where you are going.

You need to ascertain that you will regain VFR flight conditions before hitting the ground!

When you descend into the cloud your sole aim is to maintain heading, wings level and ball centered. Check your VSI to ensure that you descend at the required rate. Only use engine power to control your descent. Crosscheck your airspeed with your pitch attitude. Watch your rate of turn indicator (if you have one). You don't want to turn.

Do not maneuver. Your most reliable instruments are the slip indicator, compass (if SP-6) and airspeed. Your horizon is secondary at this stage. Remain in this attitude until you break free of cloud.

Note: this procedure is very dangerous and should never be attempted without training. Be aware that you may encounter severe turbulence inside the cloud that you will not be able to counter and that may render your horizon information invalid due to drift or exceeding the maximum rate of turn that the AHRS can measure. In this case your only option is to use the SP-6 heading together with the airspeed and slip indicator to proceed. Even so, recovery from unusual attitudes using these indicators may be impossible.

Depending on the natural stability of your aircraft, it may be best to allow the aircraft to regain normal flight regime: Stick neutral to slightly forward, engine power low, rudder center and wait...

Typical raw data recording

The image below has been obtained from raw data recorded during a touch and go. This recording was done using an SP-3 AHRS (a predecessor of the SP-7).
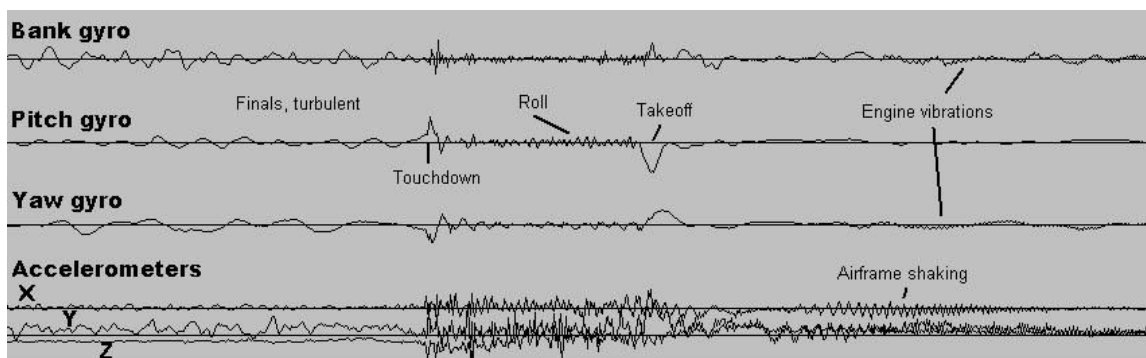
The SP-3 was installed on a ultralight aircraft. No special provision was made to dampen any engine or airframe vibrations. The SP-3 was simply taped to one of the airframe members. The resulting horizon display was correct throughout the flight. This serves to give an indication of the abilities of 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 accelerometer measurements (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 recognize, a large pitch rate of turn signals the exact point of rotation.

Climb out thereafter 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 for SP-6 and SP-7

The cannon DB9 connector (with gray shell) provides a black and red wire as well as a female RCA connector. The RCA connector connects to the RCA female Airtalk connector on your display unit using a standard male-to-male RCA audio or video cable. A good quality cable is included with each SP-6 / SP-7 unit by default.
Slightly bend the male connector shields towards the inner conductor to ensure a tight fit. Secure with a heat shrink sleeve or self-adhesive tape.
Power is supplied via the red and black cable. Connect the red cable to your 12V DC source positive (+12V). **If the SP-7 and your display unit share the same ground / negative, the black cable does not need connecting as the negative supply connection will be made through the RCA cable to the negative supply of the instrument.** The black cable is only needed should the SP-6 or SP-7 be connected to a PC or third party instrument. In this case the black cable should be connected to ground or the power supply negative. If you do not need to connect the black cable, wind it in a tight loop and isolate it using electrical tape.
If you own both a SP-6 and SP-7 you can connect both RCA connectors to a single RCA cable using commonly available RCA splitters. You need to get a splitter that provides two male RCA and one female RCA connector.

Pin Number	Pin Description
1,2	Ground (GND) / Battery minus
3	RS-232 Receive (RX)
4	RS-232 Transmit (TX)
5	Airtalk
6,7	Vin / Battery positive / +12V
8	CAN Low
9	CAN High

Cannon D-9 connector pin descriptions for the SP-6 and SP-7

Alternatively you can cut off the female RCA connector on the SP-6 and SP-7 DB9 connector, leaving you with 2 bare wires: red and green in color. Take a RCA cable of sufficient length and cut off one of the connectors. Connect the two red wires (the two red wires that use to go to the RCA connectors) to the inner conductor of the RCA cable. Connect the two green cables to the outer conductor of the RCA cable. Isolate the two conductors using electrical tape or heat shrink sleeving so they will not short to anything.
Two female RCA Airtalk connectors are provided on the larger instruments from MGL Avionics

(example Enigma, Voyager and Odyssey). You can use them both with one RCA cable to each SP-6 and SP-7 or you can use a single cable as described above.

It is suggested to install a 33V transorb plus a 10 000uF capacitor across your power supply wires if there is a possibility of power supply noise or voltage spikes caused by starter motors or other electrical equipment.

The SP-6 and SP-7 are required to be supplied through a fuse or over current protection circuit. It is acceptable to supply both through a single fuse. A fuse rating of 500mA slow blow is recommended for either one or both units.

The SP-6 and SP-7 must be connected to your supply after your main power switch (master switch). The units should not receive power when your master switch is in the "off" position.

Applications

The SP-6 and SP-7 are intended for use in 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…

It remains the responsibility of the customer buying these sensor packs to ensure that the accuracy is sufficient for his application, and that adequate sensor redundancy is in place.

Customization

The SP-7 units are designed to fulfill the need of AHRS applications in smaller aircraft (including helicopters, ultralight aircraft and gyroplanes) that do not provide a stable platform, preventing the use of many ordinary systems.

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.

SP-6 and SP-7 specifications

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

Weight (SP-6 & SP-7)
Excluding cables: 126 grams
Including cables: 175 grams (RCA signal and DB9 power cable included)

Electrical and Temperature Characteristics (SP-6 & SP-7)
Input voltage range: 8V to 20V DC regulated preferred for maximum performance.
                          11-14V is suggested as operating voltage.
Current consumption: 50 mA (heater off) at 13.8VDC input voltage
                          120 mA (heater on) at 13.8VDC input voltage
Temperature Regulation: 35ºC (internally maintained temperature)

Accelerometer Specifications (SP-6 & SP-7)
Accelerometers: MEMS
Sensor Limits: +/- 8G
Maximum G-force loading: 30G (any axis)

Rate Gyroscope Specifications (SP-7)
Rate Gyroscopes: MEMS
Maximum rate :   250º/second
Non-linearity: 0.2% FS, best straight line fit

Attitude calculations (SP-7)
Quaternion system, IEEE Single floating point, normalized.
No attitude angle restrictions in any axis.
Quaternion update rate: 40Hz
Euler angle output rate: 10Hz

Output Messages (SP-6 & SP-7)
Interface: MGL Avionics Airtalk compatible
Normal output message: 50 ms (average) latency
Raw output message: 12 ms (average) latency

Magnetic sensors (SP-6)
Sensor type: Magnetoresistive, three axis
Measurement headroom: 3:1 based on field strength at magnetic equator
Accuracy: +/-1.5º typical, sensor horizontal, clean field
Tilt compensation: Accelerometers or external gyro derived horizon
Tilt compensation range: +/-90º depending on external horizon data.