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A Rapid Mapping and Analysis System for Use During Aircraft Accident or Incident Field Investigation

S. Barter

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ABSTRACT

AMRL has developed a system to aid in the rapid mapping and the management of information gathered at aircraft accident and incident sites. This system is based on commercial mapping instrumentation which uses differentially corrected Global Positioning System (GPS) data, a medium-resolution digital camera and a geographical information system (GIS) software package. This paper introduces GPS, GIS and digital imaging, their use in the mapping and analysis of aircraft accidents, and a description of the AMRL equipment.

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Executive Summary

During the investigation of aircraft accidents and incidents, it is usually a requirement that the wreckage parts, ground marks and other interesting features at the incident site are identified and their positions recorded. This is usually carried out prior to the collection of the wreckage, to prevent the loss of evidence that may be useful in the following investigation. This is particularly important when detailed examination of some of the parts is required. The recording phase at an accident site, particularly for a large accident where aircraft parts are spread widely, can be time-consuming and very expensive in terms of resources.

The time required and expense were well illustrated during AMRL's involvement in the accident investigation of two Australian Army Sikorsky S-70A-9 Black Hawk aircraft at High Range near Townsville in June 1996. The process in the field was slow and considerable time elapsed between the initiation of the wreckage survey and the production of useable maps and the collection of the parts of interest. Only once this was completed, could analysis of the distribution to determine the point of impact in the sky commence.

As a direct result of the difficulties encountered with the Black Hawk investigation, AMRL began the development of a rapid wreckage mapping system based on the Global Positioning System (GPS) to accurately locate wreckage pieces. The data collected is fed into spatial database software along with medium-resolution digital images of the mapped wreckage. This software can be used to analyse the accident at the accident site. This allows data to be assessed on-site and added to or corrected if found to be insufficient or wrong. This system has already saved considerable time and confusion during two recent aircraft accident investigations in which the equipment has been trialed.

This paper introduces GPS, geographical information systems (GIS) and digital imaging, their use in the mapping and analysis of aircraft accidents, and a description of the AMRL equipment.

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Simon Barter, Senior Professional Officer. Graduated from RMIT with a Diploma of Applied Science in Secondary Metallurgy (1982) and a Graduate Diploma in Surface Finishing and Corrosion Control (1987), both gained though part-*time study while being employed at AMRL. He has been mostly involved with the metallurgical investigation of aircraft structures and components. These studies have included quantitative fractographic studies on Macchi, F111 and F/A-18 aircraft and research into fatigue crack growth in aircraft metals. His involvement in the investigation of numerous aircraft accidents has been the highlight of this work, having completed the Aircraft Accident Investigation course held at Cranfield Aviation Safety Centre. He now works in the Fatigue and Fracture Detection and Assessment area undertaking investigations into fatigue and fracture, aircraft accident investigation techniques and oxygen system materials compatibility.*

Contents

1. Introduction

During the investigation of aircraft accidents and incidents, it is usually a requirement that the wreckage parts, ground marks and other interesting features at the incident site are identified, and their positions recorded. This can provide valuable information about the causal factors. The process in conjunction with photography of the items being mapped, is usually carried out prior to the collection of the wreckage, to prevent the loss of evidence that may be useful in the following investigation. This is particularly important when detailed examination of some of the parts is subsequently required; their position and the condition in which they were found would often be important. The recording phase at an accident site, particularly for a large accident where aircraft parts are spread widely, can be time-consuming and expensive in terms of resources. If sufficient meaningful data is to be collected for a wreckage map to be useful, surveyors, a team conversant with the aircraft's structure, a photographer and one of the investigators will usually be required.

The time required and expense were well illustrated during the accident investigation of two Australian Army Sikorsky S-70A-9 Black Hawk aircraft at High Range near Townsville in June 1996. In this case, four surveyors were used along with two personnel familiar with the aircraft structure, a photographer and one of the investigation team. The difficult process in the field was slow and considerable time elapsed between the initiation of the wreckage survey, the production of useable maps and the collection of the parts of interest.

As a direct result of the difficulties encountered with the Black Hawk investigation, AMRL began the development of a rapid wreckage mapping system. This had become possible as a result of the Global Positioning System (GPS) being assembled by the US Department of Defence (DoD) and the development of mapping equipment using GPS signals by commercial surveying instrument manufacturers. The GPS system uses satellite signals to establish a receiver's location. Other developments have been the introduction and integration of reasonably priced medium-resolution digital cameras, the rapid rise in portable computing power and the development of spatial database software.

The use of a GPS at accident scenes is not entirely new, although, when fully developed and refined, the system described in this paper will provide considerably greater flexibility than any other current system, providing virtually instantaneous readout of wreckage maps in any format desired. The accuracy will be sub-metre (and may be considerably better in a relative sense) between points taken around an accident site.

1.1 Why map an accident site at all?

One of the most valuable and necessary activities conducted by an accident investigation team is the construction of a wreckage diagram [1, 2, 3, 4 & 5]. A wreckage diagram is a "to-scale" map of the wreckage site, noting the location of all the (recovered) wreckage, ground marks and any other notable features, either as latitude and longitude or as a bearing and distance from a reference location.

This can be a daunting and prolonged task, particularly in the case of high-speed low attitude impact, where there is usually severe structural break-up and the pieces are spread over large areas of terrain. The velocity generally determines the amount of structural break-up, whilst the angle generally determines the distribution of the wreckage. The terrain and type of surface hit may also influences the wreckage distribution.

From the examination of the wreckage distribution and impact crater it is usually possible to estimate both the velocity and attitude of the aircraft, just prior to impact. In the case of an in-flight break-up the wreckage map may, with the aid of trajectory analysis, indicate the point in space that the break-up occurred. The map may also indicate other important facts about the wreckage distribution, which can lead to the resolution of a cause of the accident. This technique is particularly important when there is no data available from a flight data recorder (FDR). However, even if there is FDR information, independent evidence that supports the first is always of value.

In significant accidents, it is normal to seek the assistance of a surveying team to map the wreckage distribution. Prior to their arrival the accident investigators would have located, identified as well as possible, tagged and visibly highlighted all the wreckage pieces of interest. It is critical that each map point be clearly recorded along with a description and photograph of the item being mapped. An aerial photograph of the site is a useful aid when overlayed with the wreckage map.

To illustrate the benefits of a wreckage diagram, the following simple example is presented [6].

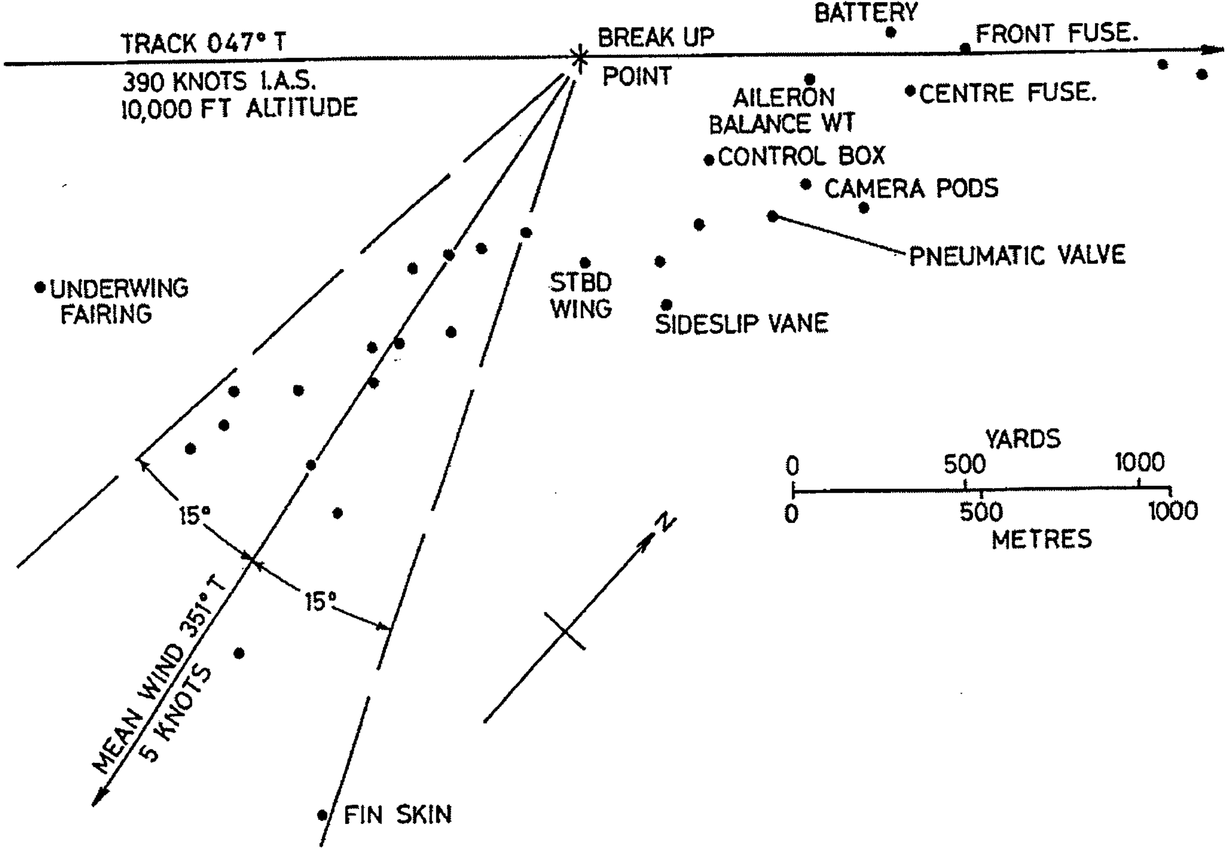

Figure 1. Wreckage map of a small drone jet aircraft that broke-up in flight over Woomera.

After a third small drone jet aircraft broke-up in-flight and several theories about the probable cause of the break-ups had been proposed and resulted in apparently unsuccessful aircraft modifications, the third accident was more fully investigated. This investigation included a detailed wreckage map. A simple version of the map is shown in Figure 1.

The aircraft's speed prior to break-up was approximately 390 knots (190 m/sec). The track of the aircraft and the prevailing wind at the time of the incident are shown on the wreckage map (Figure 1). The wind conditions were approximately constant up to the known aircraft altitude of 3,000 m. The questions the investigators had to address were - where did the break-up occur and why did it occur?

The significant factors influencing the spread of wreckage are aircraft track, aircraft velocity, gravity, wind direction and strength and part weight and drag. Heavy parts will not be significantly affected by the prevailing wind and will tend to progress in the direction of flight (battery and engine components in Figure 1) like a projectile. Light pieces should also progress along the flight path, however their aerodynamic drag will rapidly defeat the momentum forces, and subsequently the pieces will tumble to earth under the influence of the wind direction and gravity. Their weight and aerodynamic drag will determine how far the pieces travel. Caution is required to interpret the location of wing pieces and other aerodynamic surfaces, as these will tend to "fly" (generate lift) in a haphazard tumbling manner, influenced by both the original track and prevailing wind direction.

In Figure 1 the two lines drawn bound all light pieces. The intersection of these lines gives a good indication of where in space the break-up occurred – answering the first of the investigator's questions.

Methodologies for determining the trajectory of pieces, which rely on estimates of the drag, weight and initial velocity of each piece (referred to as trajectory analysis), are available in the form of computer programs. These tools will be included with the software being developed for the system described in this paper. Trajectory analysis tools can be used in the reverse sense; by back-tracking from the wreckage on the ground, an estimate of the break-up point in the sky can be made. This is also true for wreckage found in water, where the programs are modified to substitute currents for wind direction and strength and water drag for aerodynamic drag. However, even this simple example indicates the usefulness of trajectory analysis.

The location of, and damage suffered by one piece was inconsistent with the investigator's initial diagnosis, which was flutter of the wings. This piece labelled "underwing fairing" in Figure 1. was light and would have had significant drag, then why did it not fall consistently with the other light pieces? This observation did not fit the hypothesis, and was at odds with other facts; it was therefore considered more closely.

A detailed structural examination of the underwing fairing and the fuselage adjacent to this part indicated evidence of rapid cyclic loading, suggesting the onset of catastrophic aerodynamic flutter. This was consistent with the initial hypothesis. However, the location of this item on the airframe and the fact that it appeared to have left the aircraft at a very early stage of the break-up suggested flutter not of the wing but rather of the fuselage. It was found that longitudinal flexing of the fuselage dislodged the fairing, further aggravating the unsteady aerodynamic loading, which finally led to the overstressing of the airframe and the subsequent in-flight break-up. Modifications to stiffen the fuselage resolved the problem.

It is probable that had a detailed map of the first incident been completed and thoroughly analysed, two aircraft could have been saved and a lot of expensive modifications avoided. Undoubtedly the initial accidents were not fully investigated because of the expense and difficulty of the mapping required and a preconception that the problem was understood.

2. Mapping and the Global Positioning System

2.1 Positioning on the worlds surface introduction

Before discussing the system developed for mapping wreckage, it is useful to examine the "hows" and "whys" of GPS. Being a military system, there have been intentional steps have been taken to prevent a civil user from achieving the highest positioning accuracy for a system relying solely on the GPS satellite data. However, the growing demand for civil use of this highly capable system has encouraged the civil community to add other data and functions to create a system that gives high RELATIVE positioning accuracy. A More complete discussion of the history and future of the GPS system can be found in Reference 7

The GPS enables a user to define their position anywhere in the world, as long as a number of satellites are in direct "view". However, determining real world, ABSOLUTE positions incorporate all the complexities of the science of Geodesy. The following is a very brief description of the main factors affecting a GPS position.

2.1.1 Geodesy

Geodesy is the science of describing the earth's surface. The earth's surface is geometrically complex, and geodesy itself is a complex science. The aim of geodesy is to provide a practical set of rules for surveying and positioning upon the earth's surface using mathematical calculations.

The earth is not spherical, and the real shape of the earth is best described by an ellipsoid. Ellipsoids are constructed using two parameters: the minor axis and the diameter (widest part). For the earth, the diameter lies in the plane of the equator, and the minor axis lies along the spin axis, through the poles. This gives the earth the shape of a sphere that has been flattened at the poles. This mathematical figure is called a SPHEROID. Although an ellipsoidal shape describes the earth better than a spherical one, it is not precise. On land, the local topographic features (mountain ranges etc.) do not lie on a spheroidal surface. A less detectable undulation from the spheroid occurs due to changes in local gravity. The ocean surfaces are not uniform, resulting in the oceans having depressions in areas of stronger gravity and bulges in the weak gravitational areas. This gravity-induced surface is called the GEOID. The relationship between the geoid, the spheroid and land topography is shown schematically in Figure 2.

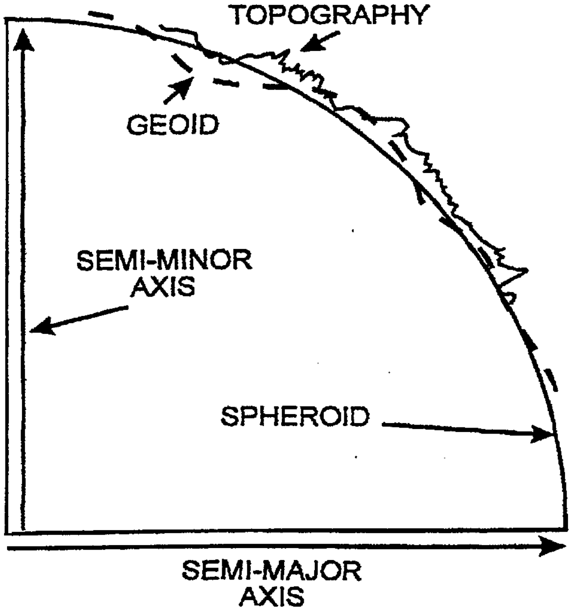

Figure 2 The relationship between the geoid, the spheroid and land topography [2]

The geoid surface is the physically real surface, which can be measured, although its irregular shape makes it impractical as a framework for surveying or navigating. The spheroid surface, being mathematically constructed is a more suitable reference to describe the earth's shape. Unfortunately, surveyors in different regions of the world have historically chosen spheroids that best matched the shape of the geoid in that local region. Today, the spheroid in any particular place on the earth is usually chosen for historical purposes (ie. all maps, etc. are referenced to that spheroid).

To relate a point on the geoid surface to a point on a particular spheroid, the two points are connected by the normal to the spheroidal surface. This provides sufficient information to enable surveyors to survey and navigate around a local region. To calculate the distance between two points on the geoid, a commonly used spheroid is chosen for that region, the spheroidal coordinates are found for the two points (normal line method), and the distance between the spheroidal points is thus calculated.

With a spheroid selected, any point on the earth's surface can be uniquely specified by three parameters: the spheroidal latitude, the spheroidal longitude and the height variation between the spheroid and the geoid. The first two quantities are often known as the geodetic latitude and longitude. The height variation between the spheroid and the geoid is very important in surveying work with satellite based systems.

Often several versions of the same spheroidal shape are in use. This is normally the case because different surveyors chose different spheroidal origins at different times, so that the spheroid surface would match some local point on the geoid. Two spheroidal frames of reference differing only by position and not by shape, are said to differ by a "datum". Any datum shifts existing in spheroidal coordinates must be compensated for when using the coordinates for surveying or navigating.

The equator is the reference line of latitude, zero degrees. The zero longitude is usually defined by a meridian known as the prime meridian. The internationally accepted prime meridian passes through Greenwich, England, but any meridian could be used. Since the earth is not a perfect sphere, there is not a unique definition of latitude and longitude.

2.1.2 Datum

A Local Datum is a horizontal survey datum that allows surveyors to establish geodetic points in an area for survey control. This type of datum uses a local marker to establish the latitude and longitude of the origin. Surveying from this point of origin is achieved by establishing the elevation of this point and maintaining the same elevation while the survey traverses over the area using the chosen spheroid for the calculations.

A World Geodetic datum or System (WGS) is a datum that uses the centre of the earth's mass as its origin (geocentric) and three axes (Cartesian coordinate system) from that origin to define the alignment. The latest of these datum (WGS-84) was established by using observations from satellites orbiting the earth over a long time, and is therefore quite recent and considered reasonably accurate.

Many datums apart from WGS-84 are still in general use throughout the Australasia region. Some of these datum are:

a. AGD-66, the Australian Geodetic Datum established in 1966, a local datum that uses the Australian National Spheroid shape.
b. WGS-72, one of the earlier earth-centred datum.
c. AGD-84, an upgraded datum from AGD-66
d. Djakada, the datum used in Java, a local datum that uses the Bessel 1841 spheroid.
e. Geodetic 1949, used extensively in New Zealand.
f. GDA-94, a new Australian datum that is very close to WGS-84.

Since there are several datum used in these areas differentially corrected GPS positions (see Section 2.8) are usually calculated on the WGS-84 datum and transformed to another datum, in the GPS receiver or in post-processing of the data. For the purposes of the GPS described in this paper, adhering to the WGS-84 datum will usually be sufficient.

2.1.3 Projections

A projection is a two dimensional geometrical transformation from the three dimensional spheroidal surface to a plane surface. Projections are used for simplicity, as it is difficult to carry around a spheroidal map! If a section of the earth has been mapped to a plane, then all the complications of spheroidal navigation can be avoided. For instance, the distance between two points is a straight line on the map.

2.1.3.1 Northings and Eastings

Most projections can be described as mapping from a spheroidal surface to a plane surface. A point on a spheroid is specified by its latitude and longitude. In a plane projection, the coordinates of a point are called its northing and easting (usually abbreviated N and E). A projection itself is defined by the equations that convert latitudes and longitudes to northings and eastings, or vice versa.

The northings and eastings are orthogonal coordinates that are often described as the X and Y coordinates ($N = Y$ and $E = X$). Typically, northings and eastings are quoted in metres. Latitudes and longitudes are angular measurements in degrees. Because of the size of the earth, as many as nine or ten significant figures may be necessary to specify a northing or easting accurately.

When working with northings and eastings, the user must be sure all functions using northings and eastings are based on exactly the same projection. This means that the projection definition should not be altered in the middle of an application.

2.1.3.2 Types of Projections

Whatever the choice of projection, one or more of the following quantities will be distorted: shape, bearing, scale, or area. This means that a compromise will need to be made in the choice of a particular projection. Usually, shape and bearing are preserved while scale and area are distorted.

The Lambert projection uses a cone placed onto the earth's surface with the cone's apex in line with the polar axis. Cones can be mathematically constructed that touche the surface along one line (central parallel) or two parallels, where the cone cuts into the earth's surface. Pure mathematical projections have been devised that convert from a spheroid to these planes. These projections keep the distortion at a minimum in the East-West direction.

The Mercator projection is calculated by mathematically wrapping a cylinder around the earth with the cylinder in line with the polar axis, touching at the equator, which will be the line of least distortion. This projection is widely used for marine navigation and most world maps. The relative scale of features varies greatly the further the projection moves from the equator, with infinite distortion at the poles.

The Transverse Mercator (TM) projection is a Mercator projection turned on its side. That is, instead of the equator being the line of no scale distortion, a line of longitude becomes the line of no scale distortion. The particular line about which the spheroid is unfolded in a TM projection is called the central meridian of that projection. As any longitude can be chosen for the central meridian, the number of possible TM projections is infinite. For any particular area, the least distortion occurs when a nearby central meridian is selected.

A specialised set of TM projections has been adopted for worldwide use. It is known as the Universal Transverse Mercator (UTM) projection. The world is divided into 60 zones; each zone (numbered 1 to 60 beginning at 180° West and continuing eastward) is 6° wide in longitude. A zone extends 3° either side of the central meridian. The mainland of Australia covers zones 49 - 56. The UTM system is used between latitudes of 84°N and 80°S.

A False Easting of 500,000m is assigned to the central meridian, a zero metre Northing to the equator for the Northern Hemisphere and, to eliminate negative values, a False Northing of 10,000,000m to the equator for the Southern Hemisphere. Australian (civil and military) maps are usually based on the UTM projection.

2.1.3.3 Vertical Surveying

When using GPS for positioning, the "Height" parameter will be height above or below the surface of the spheroid that is used for the GPS height calculation. This is NOT the height above sea level and must be adjusted for the difference between the geoidal surface and the spheroidal surface (commonly known as Geoidal Height).

2.1.3.4 World Geodetic Systems

Because of the inability of the local geodetic systems to provide a basis for expression of inter-continental geodetic information, a unified world system was developed using satellite data and other techniques. The US DoD World Geodetic System 1984, WGS-84 (as mentioned in section 2.1.2) was developed due to the need for an updated world geodetic system by the geodetic community within and without the US DoD.

The WGS-84 Coordinate System origin and axes serve as the geometric centre of the WGS-84 Ellipsoid. The accuracy of the WGS-84 coordinates of a site is significantly influenced by the method used to determine the coordinates. Depending on the data available, the WGS 84 coordinates of a site can be determined:

1. Directly in WGS-84 via GPS.
2. By a WGS-72-to-WGS-84 Coordinate Transformation.
3. By a Local Geodetic Datum-to-WGS-84 Datum Transformation.

Unfortunately there are several techniques for accomplishing a Local Geodetic Datum-to-WGS-84 Datum Transformation resulting in different errors.

Because of the distortions and surveying errors present in local geodetic datum, and the uncertainty introduced by the datum transformation, the WGS-84 coordinates of a non-satellite derived local geodetic position will be less accurate than the WGS-84 coordinates as calculated by GPS.

2.2 Introduction to GPS

The GPS is a satellite-based system operated by the US DoD. GPS provides an all-weather, worldwide, 24-hour service, which can be used for calculating positions and time. To make this system available to unlimited users, a passive ranging method called pseudoranging is used [6, 7 & 8]. The satellites are active (transmitters) and the user's units are passive (receivers). The satellite transmissions enable computation of the user's position and velocity 'relative' to a spheroid Datum. Positioning accuracy is attainable from 1 cm to 100 m, depending on the type of receiver used, antenna dynamics, number and position of the satellites in view, mode of operation and the processing (error correction) techniques employed by the user.

2.3 How the system works

Exact coordinates can be calculated for any position on the earth by measuring the distance from a group of satellites to that position. This is achieved with GPS by measuring the time-of-flight of signals from the satellites to a receiver. The satellites act as precise reference points. Assuming the distance from one satellite is known the receiver position can be narrowed down to the surface of a sphere surrounding that satellite. If the distance from a second satellite is also known, this narrows to the intersection of the two spheres, which is a circle. By adding a third satellite, the position is narrowed to one of two points. One of these positions can be disregarded because it is an unlikely answer; it is out in space or moving at high speed. By knowing how far the receiver is from any three satellites, and the locations of those satellites, the coordinates of the receiver can be calculated.

In practice, to solve for X, Y, Z, and time, four satellites are needed. The fourth measurement narrows the position down to one point, as the intersection of four spheres is one point. This is shown schematically in Figure 3.

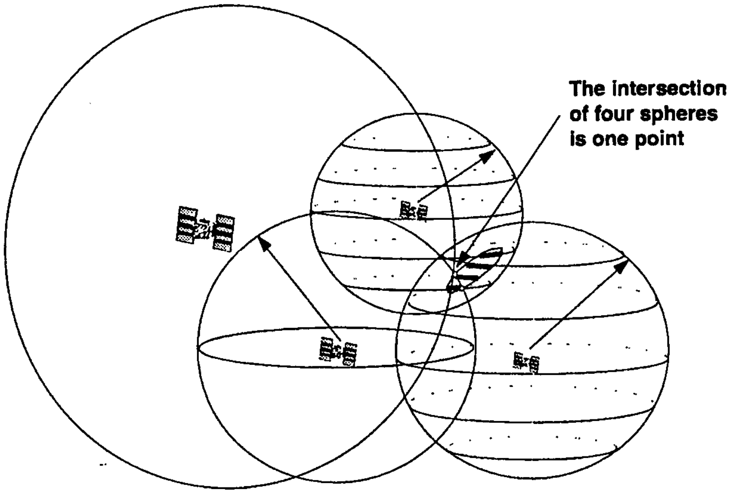

Figure 3 *Using satellite ranging to establish a receivers position in space. Four satellites are needed to produce a single point solution. (From Reference 2)*

2.4 Satellite Ranging

The distance from a single satellite is established by measuring the time taken for radio signals from the satellites to travel to a receiver. To measure the time-of-flight, the receiver needs to know when the signal left the satellite. This is achieved by generating the same PseudoRandom Number (PRN) code at the same time in both the receiver and the satellite. Synchronising the code of the satellites and receivers is essential for this process. Once synchronised, the receiver examines the incoming code from the satellite and then looks at how long ago it generated the same code. This time difference multiplied by the speed of light gives the distance. Carrying out this operation for each of the satellites being monitored will give a solution for the position of the receiver, the validity of which will depend on the number of satellites being monitored. The use of a code is important because it allows the receiver to make the comparison at any time. It also means many satellites can operate at the same frequency, because each satellite is identified by its own PRN code.

There are two positioning services available from the GPS, Precise Positioning Service (PPS)-for authorised users, and the Standard Positioning Service (SPS) - for civilian users. Due to the sophisticated yet predictable structure of the signal, it is difficult to jam, and therefore is very reliable and will work in adverse weather conditions.

Each GPS satellite transmits two radio signals [8], L1 at 1575.42 MHz and L2 at 1227.60 MHz. The L1 signal is modulated with two PRN ranging codes, P-code and CA code. The Precision or P-code (it is now known as the Y code) is encrypted for military use (PPS). The Coarse Acquisition or CA code is not encrypted. The L2 signal is modulated with the Y-code only. Most civilian receivers use the CA code to obtain GPS information. Some survey-grade receivers use Y-code as well as the CA code.

Discrimination between satellites is achieved by each satellite transmitting different codes. The use of two frequencies is to allow the user to accurately compensate for signal delays from the satellite to the receiver caused by ionospheric refraction. Since the CA code is only on one frequency, the civil user has to compensate for the delays by approximation from modelling. Buried in the signals is a navigation message, which contains the satellite orbital data, clock synchronisation correction and status information.

2.5 Accurate Timing

The accuracy of the calculations depends on both the transmitter and the receiver having highly accurate clocks. The code has to be generated in both the receiver and the satellite at the same "time". Satellites have atomic clocks that are accurate to a nanosecond. These clocks are too expensive to put into most ground receivers, so receivers use a measurement from a fourth satellite to remove any clock errors. If both the satellite and receiver clocks are accurate, an accurate position can be found by measuring the distance from the satellites. However, if the receiver clock is fast by 1 second, measuring the distance between the satellites results in intersects for only two of the satellites. When a GPS receiver gets a series of measurements that do not intersect at a single point, the computer in the receiver starts subtracting (or adding) time until it arrives at an answer that lets the ranges from all satellites go through a single point. It then works out what the time offset is and makes the appropriate adjustments to its internal clock. As the receiver clock time is an estimate, the ranges calculated are also estimates. Therefore, the ranges are called PseudoRanges

For three dimensions, four satellites (or more) are needed to cancel out time errors: four PseudoRanges plus the satellite orbit data permits calculation of a three-dimensional position (4 equations, 4 unknowns):

Latitude	Longitude	Height	Time bias (receiver clock)

So when GPS data are collected in the field, four satellites must be in view for three-dimensional data and the receiver must have four GPS channels or be able to sequence amongst four satellites.

Range measurements may be made with either the Y or the CA codes. The Y-code provides ranges with a greater accuracy, because its higher clock rate provides a shorter wavelength.

2.6 Satellite Positioning

There are 24 operational NAVSTAR satellites (SVs - Space Vehicles) orbiting the earth every twelve hours at an altitude of about 20,200 km. Four SVs orbit in each of six different planes inclined 55° to the equator. The satellites are so high that there is little atmospheric drag and their orbits are very stable.

The satellites are constantly monitored by the US DoD. The DoD has four ground monitor stations, three upload stations, and a master control station. The monitor stations track the satellites continuously and provide data to the master control station. The master control station calculates satellite paths and clock correction coefficients and forwards them to an upload station. The upload stations transmit the data to each satellite at least once a day.

2.7 Errors

The Y code pseudoranges can be measured to about four metres RMS. The CA code pseudoranges can be measured to about 10 - 15 metres rms. At 2drms[1] the pseudoranges are about 21m and 100m in the horizontal and 28m and 156m vertically, respectively. These figures are estimates of the error distributions for ideal operation. The user position accuracy depends on many factors. For instance the geometrical relation between the satellites tracked can further degrade the pseudoranges. The performance degradation caused by poor geometry between the satellites can introduce an error called Dilution of Precision (DOP).

This will multiply the effect of any errors in the pseudoranges caused by atmospheric conditions (ionosphere, troposphere), multipath reflections, satellite orbit errors, receiver noise, satellite clock errors, vehicle dynamics and Selective Availability (SA). These error sources along with methods used to correct for them, are defined below.

2.7.1 Dilution of Precision

DOP expresses the effect of satellite/user geometry on the accuracy of the solution. As satellites become more closely grouped in the sky the accuracy of the positions calculated drops. To prevent this, tracking more that 4 satellites allows the receiver unit to select the best positioned satellites to produce the best accuracy. High quality receivers will usual be configurable to reject positions taken when satellites are in poor positions. There are various types of DOP:

PDOP = position DOP (radial 3-dimensional), made up of;
- HDOP = horizontal DOP (2-dimensional, horizontal only)
- VDOP = vertical DOP (vertical only), and

TDOP = time DOP

High quality receivers calculate the DOP continuously and warn the user or refuse to collect a position if the DOP is above a threshold value. Some receivers allow the DOP mask to be set by the user, guaranteeing that this source of error is mostly eliminated. Naturally as a receiver is required to switch from SV's in poor DOP positions to other better placed SV's, it is useful if the receiver can track a large number of SV's.

2.7.2 Ionospheric and atmospheric delays

The distance calculations assume the GPS signal travels at a constant speed, the speed of light. Unfortunately, the speed of light is constant only in a vacuum. Once the GPS signal enters the ionosphere (140 to 200 km above the earth's surface) and the troposphere (our weather) the signal slows down, resulting in incorrect range calculations. High quality GPS receivers do some corrections for these delays, or may use comparisons between the two frequencies transmitted to correct for these delays.

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[1] Since the position given by the roving receiver is an estimate calculated from the pseudoranges taking into account any corrections for errors, the result is a probability position. Typically, this is denoted as either rms or 2drms, which refers to the number of standard deviations from the mean for that position ie. Rms is the probability that the position will be within a stated diameter 68% of the time, 2drms – 95% of the time and 3drms – 99% of the time. GPS accuracy is usually stated for the 2drms case.

2.7.3 Receiver and satellite clock errors and satellite position errors

Atomic clock and satellite orbit errors can occur, but are minor and are adjusted by the US DoD from the monitor stations.

2.7.4 Multipath interference

This occurs when the signal is reflected off other objects at or near the earth's surface. The reflected signal interferes with the line-of-sight signal. Advanced signal processing and well-designed antennas help minimise this. Typically, a ground-plane antenna with a 15° mask is used. Masking out multipath interference in hand held GPS units (with integral antenna) is difficult.

2.7.5 Selective Availability

Due to the performance that can be achieved by tracking the CA code, the U.S. DoD introduced a significant source of error called Selective Availability (SA). SA is an artificial degradation of the satellite signal's synchronisation and orbital information. It causes errors in a GPS position of up to 100 meters (2drms). SA (along with some other sources of error) can be removed using a technique called differential correction.

2.8 Differential Correction

Differential correction is a technique that greatly increases the accuracy of the collected GPS data [9]. It involves using a receiver at a known location, a base station, and collecting GPS positions at unknown locations with other receivers (often referred to as "rovers").

The data collected at the known site is used to determine what errors are contained in the satellite data by comparing the calculated position against the known position of the base station. The information from the base station is then applied to the data collected by the rovers and the offset differences are used to remove errors from the positions. To do this the base station position needs to be known very accurately as differential correction position accuracy depends on the accuracy of the coordinates of the base station. There are two methods for performing differential correction, real-time and postprocessed.

2.8.1 Real-Time Differential Correction

In real-time differential GPS, the base station calculates and broadcasts (through radio signals) the error for each satellite as it receives the data. This correction is received by the rover, which applies the correction to the position it is calculating. The result is that the position displayed by the receiver, is the differentially corrected position. These corrected positions can be saved to a file in the data collector, and may be used immediately to generate, or update accurate maps with supplied software (either within the data collector (if capable) or on some other computer). Since the errors due to SA, satellite orbital and clock inconsistencies, and atmospheric effects will be similar for receivers tracking the same satellites through similar regions of the sky, all of these errors can be virtually eliminated. The degree to which this can be achieved is dependent on how close the two receivers are, as both the base station and the rover must track the same satellites. Typically, the error of the position collected increases by 1 in 10^6 ie. 1m for 1000km, since tracking a satellite from two different positions will result in slightly different errors (path through the atmosphere, satellite orientation etc.). Usually correction services recommend that the rover should be limited to less than 500km from a base station.

2.8.2 Postprocessed Differential Correction

In postprocessed differential GPS, the base station records the error, at the station, for each satellite directly into a computer file. The rover records the field positions in a computer file. After returning from the field, the two files are processed together in the software and the output is a differentially corrected rover file.

2.9 GPS Mapping System Components

To create maps using GPS equipment it is necessary to log data and to correct that data.

2.9.1 Receivers

GPS receivers are usually classified by the number of "channels" they have. They may calculate positions as often as once per second and provide accuracy from cm to 10 meters with differential correction processing and up to 100m without. The receivers vary in size, weight, and number of positions they can store.

A GPS receiver "channel" consists of the digital and analog hardware necessary to track the signal from one GPS satellite at one of the two transmitted frequencies. A "correlation channel" is the part of the hardware that uses a circuit to maintain alignment between the received code and a code replicated by the receiver. A "squaring channel" is used to produce the second harmonic (double the frequency) that is locked to the incoming signal. This removes the code on the signal, allowing the recovery of the unmodulated carrier wave of the satellite's transmission. The carrier wave can be used for smoothing and high precision relative positioning.

A continuous tracking channel continuously tracks one frequency of one satellite for a long time (many minutes to hours). A slow switching channel switches between satellites at a slow rate refreshing the satellite orbital data (almanac). This may provide the ability to preacquire a satellite. This would be needed for switching to another satellite if the geometry of the satellites being used deteriorates (DOP).

A "multiplexing" channel is one that can switch rapidly between satellites. This may be required in high dynamics situations, such as aircraft etc. The performance is not as good as dedicated continuous tracking. The cheaper hand held GPS units often use a single multiplexing channel rather than several channels. For high accuracy, use of the satellite's signal carrier wave and differential correction along with constant, multiple satellite tracking will be required.

Apart from position and time information GPS receivers will also compute velocity and heading when moving, allowing navigation between positions.

2.9.2 Data Collectors

Data collectors are handheld, pen-based, or portable computers running data collection software. Some data collectors allow information about positions (attributes) to be logged, which are data tagged to positions, while some only store positions. The data logging software controls the GPS receiver. Parameters can be set to control how often positions are taken, when positions are taken, and how much GPS data are stored

Data collectors vary according to; size, weight, the type of data they store, the type of physical environment they are suitable for, and the amount of information they store. They may vary from hand held devices to fully optioned computers (laptop or other). Some data collectors must be connected to a separate GPS receiver. Some combine the GPS receiver and the data collector in a single piece of hardware.

2.9.3 GPS Software

Each GPS mapping system comes with processing software. After returning from the field, the software can download the position and attribute information from the data collector to a PC. The software may then improve the accuracy of the data using post processing differential correction if required. Since some data collectors calculate the differentially corrected positions in real time, correction data will be needed during data collection. This may be supplied by an inbuilt receiver or another external receiver, receiving correction data from a correction service or a transmitter at a known location.

The software can display the GPS data as tables of positions. Some programs provide editing functions so position and attribute data can be manipulated, adjusted, or deleted. Some software also provides plotting functions. The software packages vary according to the number of editing features and the range of export options.

GPS captures geographic positions and time. These data are usually referenced to a description and name of the feature. These attribute and position information are ideal for input into Geographic Information Systems (GIS) or other spatial databases (a database where information is referenced to positional data). The GPS processing software will exports data in standard formats so that it can be used in a GIS package. Here it can be combined with information from other sources for further mapping and analysis. Some GIS packages have the GPS software as a module of the main GIS package

3. Introduction to GIS

3.1 Introduction

A GIS is a computerised database designed for the capture, storage, analysis, and display of spatial data. GIS technology integrates common database operations with the visualisation and analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make them valuable for explaining events, predicting outcomes, and planning strategies. Other software packages that can be used for mapping include computer-aided drafting and design (CAD) systems, computer-aided mapping systems, automated mapping and facilities management systems, or land information systems. All of these can simply be referred to as GIS.

Mapmaking and geographic analysis are not new, but a GIS performs these tasks better and faster than the old manual methods. GIS systems are computer based, the hardware being the computer. The software will usually run on a wide range of operating systems, from mainframes to desktop computers (stand-alone or networked).

The GIS software provides the functions and tools needed to store, analyse, and display geographic information. The software includes tools for the input and manipulation of geographic information, a database management system (DBMS), tools that support geographic query, analysis, and visualisation, and a graphical user interface (GUI).

The most important component of a GIS is the data. Geographic data and related tabular data can be collected in the field or fed in from other sources, such as maintenance records, maps, or witness statements. A GIS will integrate spatial data with other data resources. A GIS can also usually be interconnected to an organisation's DBMS.

GIS technology is of limited value without someone to manage the system and develop plans for applying it to problems. GIS users range from the specialists who designed, and maintain the system to those who will use it to help perform an investigation.

3.2 How GIS Works

A GIS stores information about the world as a collection of data layers that can be linked together by geography. This concept has proven invaluable for solving many real-world problems from tracking vehicles, to modelling global atmospheric circulation.

3.2.1 Geographic References

Geographic information contains either an, explicit geographic reference, such as latitude and longitude, or an implicit reference such as an address, name, and number. A process called geocoding is used to create explicit geographic references (multiple locations) from implicit references (descriptions such as addresses).

These geographic references allow you to locate features (such as a witness position or fence line, and events, such as an explosion) on the earth's surface for analysis.

3.2.2 Vector and Raster Models

GIS work with two fundamentally different types of geographic models—the "vector" model and the "raster" model. In the vector model, information about points, lines, and polygons is encoded and stored as a collection of x, y & z coordinates. The location of a point feature, such as a piece of wreckage, can be described by a single x, y, & z coordinate. Linear features, such as roads and fences, can be stored as a collection of point coordinates. Polygonal features, such as impact craters and fire marks, can be stored as a closed loop of coordinates.

The vector model is extremely useful for describing discrete features, but less useful for describing continuously varying features such as vegetation type or part damage. The raster model has evolved to model such continuous features. A raster image comprises a collection of grid cells rather like a scanned map or picture. Both the vector and raster models for storing geographic data have unique advantages and disadvantages. Modern GISs are able to handle both models.

3.2.3 GIS Tasks

Geographic information systems will usually allow the performance of five processes or tasks:

Input
Manipulation
Management
Query and Analysis
Visualisation

3.2.3.1 Input

Before geographic data can be used in a GIS, the data must be converted into a suitable digital format, and/or transferred from digital field-collection equipment. Paper maps and other hard copy can be digitising. This can be achieved by using scanning technology. As well as these, transferring data from databases, or collecting images with digital cameras, are excellent sources of data. Many types of geographic data already exist in GIS-compatible formats, such as from manufactures, commercial or military databases, or government mapping agencies.

3.2.3.2 Manipulation

It is likely that data types required for a particular GIS project will need to be transformed or manipulated in some way to make them compatible with the GIS. Before the information can be integrated, it must be transformed to the same scale (degree of detail or accuracy) as the data presently in the GIS. This could be a temporary transformation for display purposes or a permanent one required for analysis. GIS technology offers many tools for manipulating spatial data and for removing unnecessary data.

3.2.3.3 Management

For small GIS projects, it may be sufficient to store geographic information as simple files. However, when data volumes become large and the number of data users becomes more than a few, it is often best to use a database management system (DBMS) to help store, organize, and manage data. A DBMS is nothing more than computer software for managing a database.

There are many different designs of DBMSs, but in GIS, the 'relational design' has been the most useful. In the relational design, data are stored conceptually as a collection of tables. Common fields in different tables are used to link them together. This simple design has been widely used primarily because of its flexibility and very wide deployment in applications both within and without GIS.

3.2.3.4 Query and Analysis

Once a functioning GIS containing the required geographic information has been assembled, questions can be asked, such as in the case of an analysis of an aircraft accident: which parts fell the furthest from the accident site? How far is it between two pieces of wreckage? Were all the parts of the wing accounted for?

GIS provides simple capabilities such as point-and-click query, and sophisticated analysis tools. GIS technology is most useful when used to analyse geographic data to look for patterns and trends and to contemplate possible scenarios. A modern GIS may have many powerful analytical tools, but two are especially important.

Proximity Analysis
How many wing parts lie within 100 m of the main wreckage?
Where is the centre of mass of the engine parts?
What is the bearing to the impact crater?
How far away was a witness who saw a fireball, and in what direction were they looking?

Overlay Analysis
The integration of different data layer. At its simplest, this could be an operation such as displaying an image of a part over a map of the parts positions. Analytical operations require one or more data layers to be joined physically.

3.2.3.5 Visualisation

For many types of investigation, the result is best visualised as a map or graph. Maps are very efficient at storing and communicating geographic information. Over the traditional mapping methods, GIS provides new and powerful tools to extend the art and science of cartography. Map displays can be integrated with reports, three-dimensional views, photographic images, and other output such as multimedia (video, audio etc.). For instance, virtual fly throughs of the accident site can be generated. Naturally, the extent to which these capabilities will be required will depend on the accident that is being investigated and the data available.

3.3 Data for a GIS

A GIS allows the integration of data that has been collected at different times, at different scales, and using different methods of data capture. Sources of data include maps on paper or transparency, written data, digital files, and information stored in human memory. Without GIS, integrating data in different formats, from different times, and at different scales, is usually difficult.

In the past, data has been captured for a GIS by digitising existing maps, manually entering textual data, and scanning in information. There are limitations with these methods. Original maps are often out of date, contain transcription errors, and may not be in a suitable scale. A GIS is only as good as the information it contains. Poor quality input data causes erroneous or meaningless information.

GPS allows accurate, up-to-date data to be collected when and where it is need, at relatively low-cost. With the GPS mapping tools currently available, a data dictionary can be defined so that attributes can be collected in a standard format in the field at the same time as position data is collected. This is fast, eliminates transcription errors, and ensures that the information in the database is current and consistent.

3.3.1 Data Types

There are two main types of data in a GIS - cartographic and nongraphic.

3.3.1.1 Cartographic Data

Cartographic data is map information stored in a digital form. It is the geographic features described on a map. These features are classified as points, lines, and polygons. (Polygons are also called areas or regions.) Every entity on a map can be defined as a point, line, or polygon.

Points:
A point represents a feature that has only one geographic location (latitude, longitude and height). Examples of point features in the aircraft accident investigation role may include small wreckage parts categorised according to type, trees and fence posts.

Lines (Arcs):
A line is made up of a series of connected points. It is one dimensional, having length but no width. Examples of line features include rotor blade slashes, fence lines, roads, and ground skid marks.

Polygons (Areas):
A polygon is an area enclosed by lines. It is two-dimensional; the area enclosed by a polygon has length and width. Examples of polygon features include areas of ground fires, impact crater perimeters, and large wreckage parts.

3.3.1.2 Non-Graphic Data

The second type of data used in a GIS is non-graphic. This is descriptive information stored in the database about the features (points, lines, and areas) located on a map.

The descriptive information is called an attribute. An attribute common to all features is geographic location, which for example, could be given the attribute name LOCATION. Other attributes depend on the type of feature and its characteristics that may be important for a particular purpose or application. For example:

> Wreckage parts have names, may be given a number, will have notes attached and may have one or more images attached.
>
> A road has a name and a surface type

Each of these characteristics can be specifically identified in a GIS by giving it an attribute name, such as PART-NAME, PART-NUMBER, NOTE, ROAD-NAME, and/or IMAGE.

Each attribute has a set of possible values called the domain. The domain for the attribute ROAD-NAME is all road names in the area of interest. Each instance of a feature has specific attribute values associated with it. For example, roads in general have names, but a particular road has the name **Forest Road.** The attribute ROAD-NAME is an attribute of all roads, and **Forest Road** is the value of that attribute for a specific road.

3.3.2 Data Structure

There are two types of data structure - topology and layers. Topology refers to the underlying spatial relationship connecting features. Topologies provide the logic that connects points, lines, and polygons to each other, and are not usually edited after data capture with a GPS. Layers provide a way to structure and present the data.

3.4 Collecting GPS Data for a GIS

GPS units are excellent data collection tools for creating and maintaining a GIS. There are some specific issues to be aware of when using GPS to collect GIS data. This section looks at reasons for using GPS to collect GIS data. It also covers what should be considered when preparing to collect GPS data, collecting GPS data in the field, and what to look out for when processing the data.

There are a number of ways to capture data for a GIS: digitising or scanning existing maps, using aerial photographs and photogrammetry, manually typing text into a database, and transferring files from other sources.

It is important that the data entered into a GIS is accurate. A GIS enhances decision making and analysis, but the value of the information derived from a GIS is only as good as the data entered into it. GPS is an excellent tool for collecting accurate geographic data.

With other data capture methods errors are introduced during data transcription, text entry, and digitising. Because the GPS data is collected in a digital form, it is fast and easy to transfer directly into the GIS database. Transcription errors are eliminated.

Often there are insufficient funds and time to collect all the data to the required level of accuracy using traditional surveying methods. Here the speed with which GPS data can be collected is a great advantage.

3.4.1 Data Collection Considerations

Deciding what data are to be collected is a critical part of the data collection operation. This requires thought about the amount of data that is to be collected, the structure of the data and how the GPS data fits in with existing data such as existing descriptions of a particular aircraft's parts. Carefully planning before beginning the collection of data will save considerable time latter.

For a GPS mapping system that allows the collection of feature and attribute data, it will be necessary to use the GPS software to create a data dictionary. A data dictionary is the equivalent of a paper form; it lists the features that are to be collected. It is transferred to the data collector so that in the field the operator is prompted to enter the appropriate features and attributes. Creating a data dictionary is important to ensure that the data collected in the field provides the correct answers once it is in the GIS.

Some items that should be addressed when creating a data dictionary are:

1. The number of features to be collected? How restrictive is the data dictionary? Most data collectors have a finite number of data points that can be collected. This is governed by the internal memory of the data collector. The data collector keyboards are usually difficult to use, which will limit their usefulness in the field, therefore using menus will be useful.
2. How should the data be structured? This is of primary consideration as the ease of viewing the data, for the purpose of analysis, is governed by the categories (features) into which the data is allocated in the field. It is a time consuming job to reorder the data once collected.
4. How will the data be collected? Should post processing be used or should realtime corrected data be relied upon? In the case of aircraft accident investigation, realtime corrected data will usually be the most useful due to the remoteness of many accident locations and the need to have accurate maps at an early stage of the investigation.
5. How will the data be processed? Limitations in the data collector software or the GIS package may limit the manipulation of the data. A though knowledge of the packages will allow efficient use of the data logger.
6. Will the data need to match existing data? Standardised data sets should be used where possible. This may require standard data sets for particular aircraft types or accident types.
7. Consider the units, datum and coordinate system to be used. To match existing data the same units, datum and coordinate system should be used. The ISO unit system will probably by used along with the WGS84 datum and the local UTM projection. Northings and eastings will usually be denoted in decimal degrees.

3.4.1.1 When and Where to Collect Data

Usually it will be necessary to identify where the data is to be collected. In the case of an aircraft accident site, marking the wreckage prior to the mapping phase will allow a general view of the extent and type of data that will need to be collected. During this, it will be useful to build an outline of the types of features and attributes to be collected, which will be most useful for the analysis of the accident. Because of this, refining the data dictionary will be necessary prior to the commencement of the data collection phase. Other considerations will be to decide on a start point and a route that makes the data collection as efficient as possible. Some accident sites may require data collection over many days. Position-to-position accuracy will be best if the points are taken at similar times. This is due to the errors being the same for positions taken close together in time. Therefore, plan to collect closely spaced positions as a 'block.'

The field conditions including weather, size of area to be traversed, accessibility of terrain, and obstructions that can affect satellite visibility at different locations, will need to be taken into account. Accuracy is affected by the relative positions of the satellites. With the completion of the satellite array by the US DoD, lack of satellites is no longer a major problem unless some of the sky is masked by terrain, buildings or trees. The GPS processing software will usually include a mission planning option that allows planning of the best time to collect data. This option will show the estimated positions of the satellites at any given time.

3.4.1.2 Collecting Data in the Field

The specific steps for collecting data in the field are usually covered in the data collector's manual for the specific software being used. This section covers a few general points to keep in mind when collecting data.

How data is collected is determined by the capabilities of the mapping system and by the operators preparation. If a standard data dictionary is to be used with or without modification, the operator can open a file and select the feature to record. If a data dictionary is not available, recording one feature per file can be used; for example, one wreckage part per file or one road per file. The feature can be identified by entering a note or by giving the file an identifiable name.

Naming files is an important part of collecting and processing data. To keep track of data sets, a file naming convention should be established. GPS data collection can result in an enormous quantity of data being generated quickly. Keeping track of that data can become a problem if the files are not properly managed. All personnel using the equipment should adopt the same conventions and use them consistently.

3.5 GPS Data Accuracy

GPS accuracy can range from less than a centimetre to more than 100 metres depending on the equipment, data processing techniques, and other factors. To some extent, the accuracy of the data depends on the operators knowledge and skill in using GPS technology.

The horizontal coordinates derived from GPS are typically two to five times more accurate than the vertical coordinates for any given GPS position. This is due to the shallow angle that the satellites are usually situated, in reference to the rovers position on the earths surface. When techniques and equipment yield a measurement of a centimetre horizontally, the associated vertical accuracy is of the order of 2 to 5 centimetres. This becomes a significant factor when using techniques and equipment that yield only 2 to 5 metres of horizontal accuracy. The associated vertical accuracy could be as low as tens of metres.

3.6 Offsets

Often it will not be possible to capture a position near an obstacle due to masking of a part of the sky, and therefore a view of some of the satellites. Most GPS data collectors allow the recording of the position of a geographical feature, without actually having to position the GPS receiver antenna directly over that feature. This facility is very useful since, apart from the masking of satellites, it may be difficult, inconvenient or even impossible to position a GPS receiver over a feature and obtain GPS positions.

An offset is a 3-dimensional modification to the GPS position. Offsets can be used to record the full 3-dimensional position of completely inaccessible features such as the top of a tree, a ledge partway up a cliff, etc. An offset for a point feature consists of a bearing (an angle from either true or magnetic north), a range (slope distance), and inclination (angle above or below the horizon). An offset for a line feature or area feature consists of a direction (left or right) relative to the direction of travel at the time the feature is recorded, a range (slope distance), and an inclination (angle above or below the horizon).

Some examples where offsets might be used are:

- When capturing a tree feature or a piece of wreckage adjacent to a tree, it is typically easier to stand some distance (eg. 10 paces to the North) from the tree and record its attributes. This is to ensure good GPS reception, and to be able to see the tree itself clearly, noting any cuts, impact marks etc. The offset can then be specified ie '10 m South'. This ensures that the tree is positioned correctly in the GIS. This is an example of an offset point feature.

- Offset line features may be captured, for instance, while moving ie driving along a road and recording a fence line, an offset of say - 3.5m to the left could be used. This will position the fence 3.5m off the left-hand-side of the road.
- When capturing an area feature, such as an aircraft fuselage, it is generally easier to ensure GPS coverage by walking around the aircraft fuselage at a distance of, for instance, 5 m. An offset of '5 m to the right' (presuming clockwise movement around the fuselage) would be entered into the data collector, so that in the GIS the outline of the fuselage will be accurately recorded.

Offsets can be collected in several ways. Typically, for short distances, a tape measure and a compass will suffice (or an estimate of distance and bearing if the position does not need to be known very accurately). For more demanding work, such as plotting wreckage in deep valleys, or on the ocean floor, specialised measuring equipment may be needed. For use on land a laser range finder, compass and inclinometer will supply sufficient data to calculate the offset over about 500m. For under sea work sonar (side-scan) may provide adequate information to calculation of the offset.

Several of the higher quality receivers and their data loggers will accept this offset information directly, such as from laser rangefinders, digital compasses and inclinometers, among other external sensors.

4. Digital cameras

To fully utilise the information gathered at an accident site, it is important to have rapid access in a readily digestible form. One of the ways that the usefulness of the GIS can be extended is to include image data with the notes and geographic positions. Although, it is possible to digitise conventional photographic prints, or just cross reference these prints to locations in the GIS, it will be much easier to analysis the accident if the images are, to begin with, held within the GIS data base. This, of course, will eliminate the delay that comes with conventional processing and printing. The easiest method of collecting digital images is with a digital camera.

Digital camera technology has progressed considerably in the past few years. Reasonable resolution is now offered (typically about 1000 x 1500 pixel), and many useable features, such as a LCD preview and review screen on the camera. Their price has reduced to reasonable levels - comparable to video cameras.

4.1.1 Digital camera resolution

Although digital camera resolution has improved, the resolution of a conventional (analog) cameras using 200ASA film (as preferred by many investigators) is still superior. 200ASA film has resolution of about 60 to 80 lines per mm. This equates to about 2880 X 1920 points on a 35mm film negative frame, against the 1500 x 1000 pixel for a medium resolution digital camera. Very high quality black and white film (such as Kodak's Technical Pan) can have resolutions up to about 600 lines per mm giving a 36mm X 24mm negative a resolution of 21600 X 14400 points. Added to this, conventional colour film has superior colour rendition and black and white film has superior dynamic range. Clearly, if high resolution and precise colour rendition are required, then conventional photographic methods will be required.

Although, conventional film has a general resolution advantage over most digital cameras, there are still considerable advantages, to the accident investigator in the convenience of digital photography. These advantages will be expanded later, firstly, an examination of imaging resolution versus output resolution will be considered.

Ideally, the resolution of a digital camera should equal or be better than the output device's resolution. For fine point or line resolution, it is some times necessary to have at least twice the resolution of the fine detail, if 'aliassing' is to be avoided. Aliassing is the problem where the image pixels may fall between the presented detail resulting in either the line, or point being lost or the pixels on either side of the line or point being used to image the line or point. This can result in the line either, disappearing or becoming jagged, or the point disappearing or being displaced. Some software may contain fixes to minimise this problem.

Table 1 shows the one-for-one, resolution requirements to fully utilise typical output device resolution.

Table 1 – Maximum digital resolution requirements

Output device type and resolution	Photographic resolution of printer*	162.5 X 254mm (8' x 10") print	127 x 178mm (5" x 7") print
Typical dye-sublimation printer 300 dots per inch (dpi)	300dpi	2400 x 3000 pixels	1500 x 2100 pixels
Typical colour laser 600dpi	150dpi	1200 x 1500 pixels	750 x 1050 pixels
Top of the line ink jet printer 1440 dpi	360dpi	2880 x 144000 pixels	1800 x 2520 pixels

*The resolution of printers can be somewhat misleading, as it depends largely on the nature of the dots applied to the paper. If the dots can not be varied in size or intensity then to render shades the number of dots must be varied, and to render colour the number of dots of each colour plane must be varied. Therefore, a single pixel may require a number of dots. The effect of this, when compared to photographic prints is that up to four dots will be required to render one pixel - one each for cyan, magenta, yellow and black (printers usually use four colour planes). Dye-sublimation printers can apply several colour layers and vary intensity of the colour to a single dot, therefore producing dots in a similar manner to print film. Unfortunately, dye-sublimation printers tend to blur edges because of dye spread. This gives their output a 'softer' appearance compared to other types of printer.

Resolutions below the printer resolution will, on most occasions, be adequate, indeed resolutions of 1500 X 1000 have been found suitable for most investigation and presentation applications. Higher resolutions require larger memory capacity. Large memory use has penalties in slower manipulation times, requirements for faster computers with larger memory and storage devices, a larger memory for the camera, and slower picture save and transfers.

4.1.2 Digital camera colour

Conventional colour film uses three different dyes (in effect three sets of colour sensitive emulsion layers, each activated by a particular colour) to render colour, whereas most digital cameras use a single detection device. This detection devise only 'sees' in black or white. Colour is produced by having a coloured mask over the detection chip with each of the three colours covering a percentage of the pixels. The computer in the camera then estimates the level and placement of colours according to the information from the pixels. The selection of the mask used and the sophistication of the processing software account for the finished result. Generally, this method of colour rendition is not as good as conventional photographic processes. The use of three detection devices will improve the colour rendition, as will taking three pictures with three different coloured filters. Unfortunately, such methods are either expensive to implement in digital cameras or require the camera and the subject to be stationary for an extended time interval.

The other main colour limitation of most digital cameras is that the dynamic range of the colours is restricted to eight bits each ie 256 shades for each of the three colours. This is called 24-bit colour (3 x 8 bit), which will give about 16 million colours. Conventional cameras effectively have a continuous graduation of colour over their entire range. The more expensive digital cameras do have 10-bit depth, which will give improved colour rendition. It is generally accepted that each colour plane should have 12 bits (4096 shades), or 36 bits in total, to match the dynamic range of colour slide film.

Although, colour rendition is not always good with digital cameras it is usually adequate for the investigator. Colour correction can be achieved with image processing software. Taking a photo of a standard colour chart prior to each session of field data collection, or at the time a critical item is photographed, then using this image as a correction guide during software processing, will overcome most of the colour rendition problems.

4.1.3 File compression [10]

Since digital images are memory intensive, a form of file compression is usually applied. For a 1.5 million-pixel image, the file size directly from the chip (raw image) will be 1.5 Mbytes (for an 8 bit image). This image may be in TIFF format. The camera's computer then calculates the three colour planes to produce a 4.5Mb colour image (probably in TIFF format). Naturally storing a large number of 4.5Mb images would require a large memory, so the camera's computer compresses the image using one of several compression formats and levels of compression, and then stores the compressed image. JEPG is the most common compression format used although there are a large number of formats available - some of the newer types offer greater compression with less loss of information (MRSID is one). Compression will degrade the image and may, add artefacts as shown in Figure 4. The degradation and artefact addition may limit image manipulation. For these reasons it is best to use the least lossy format allowed by the camera, or, preferably the uncompressed image format. After the image is prepared for display, it can then be compressed for storage. The ability to store and transfer uncompressed images is one of a number of considerations when choosing a camera.

Figure 4. A low resolution image of a piece of aircraft wrekage showing the pixels. The image on the left was 76k on disk which was compressed to 24k on disk in the right hand image. Note the 8 x 8 pixel block artifacts that the JPEG compression algorythm has imposed on the image.

4.1.4 Digital camera advantages.

The convenience of digital cameras over the conventional cameras and film, has a lot to offer the field investigator:

1. Images taken with a digital camera are available for viewing either on a camera LCD screen or after downloading to a computer at the site. This allows further photography of critical items, if the initial images do not show what the investigator intended.
2. A large number of images can be sorted and stored in a database, and transported to other computers for other investigators to inspect.
3. Manipulation (lightening, darkening, cropping, reducing or enlarging, sharpening or smoothing, making montages etc.) can be carried out on site to produce a finished image that best presents the evidence of importance to the investigator.
4. Annotations, beyond those available to conventional cameras, can usually be inserted directly on to the image. Even voice annotations can be included with images on some cameras.
5. The independence of processing facilities may be important in situations where the accident has occurred at a remote site.
6. The digital images can be transmitted directly to the investigators home base or a consultation laboratory, for comment.
7. Digital images do not require processing a possibly unsecure facility

4.1.5 Selecting a digital camera for field use

This section is only intended as a guide to some of the important considerations when selecting a digital camera for accident investigation field uses. Further information about digital cameras can be gathered from numerous other sources.

The most important initial aspect for consideration is the number of pixels used by the camera to produce the image - the higher the better. Here the discussion has been centred around 1.5 million pixel cameras, unfortunately there are several ways in which manufactures have produced this sort of resolution - The simplest, although probably one of the more expensive methods is simply to use a 1.5 million pixel detection chip. Other cheaper methods (the larger the chip the more expensive it is) involve using three smaller chips or one smaller chip with oblong pixels and a special masking technique. Although these methods would appear to be inferior, they are still capable of producing reasonable results. Figure 5 shows two views of the same piece of wreckage, the first is taken with a digital camera and the second is from a scanned in conventional print taken with a high quality SLR camera. Both images have the same resolution (if the images were to be shown here in their entirety they would be about seven times larger in area). Both views have sufficient detail for accident investigation purposes although the scanned image appears a little better. Note also that the lighting was different for each of these images, and the conventional image was taken with fill flash.

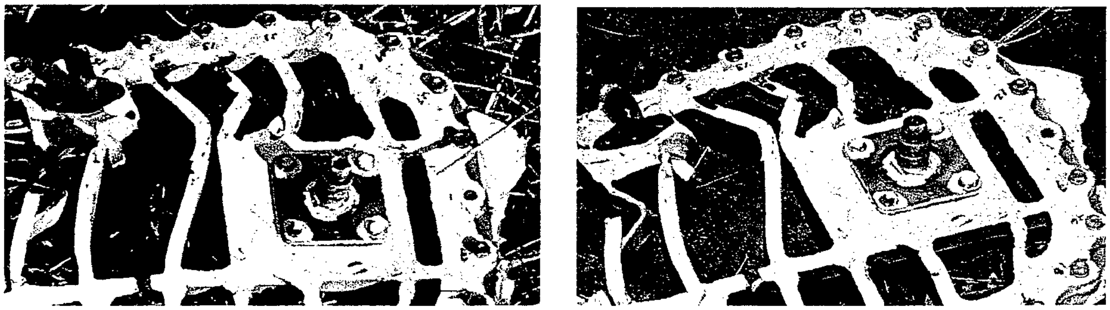

Figure 5. Two views of the same piece of wreckage (different backgrounds). The first was taken with a digital camera and the second is from a scanned conventional print taken with a high quality SLR camera. Both images have the same resolution (if the images were to be shown here in their entirety they would be about seven times larger in area). Both views have sufficient detail for accident investigation purposes although the scanned image appears a little better.

Other considerations, in no particular order of importance, may include:

The quality of the camera and reputation of the manufacturer.
The compression method used in the camera.
The ease of down loading the images to a computer.
The robustness of the camera.
The weight of the camera.
The quality of the camera software.
The general capabilities of the camera - changeable lenses, zoom lenses, built in flash, batteries requirements etc.
The cost.

5. The AMRL wreckage mapping system

5.1 Introduction

The system chosen for integration by AMRL utilises a 12-cannel GPS receiver incorporating a multi-channel correction receiver mounted in a single box and carried in a bum bag. A hand held, weather resistant data logger or computer can be connected to the receiver. Included with the equipment are a medium resolution (1.5 million pixel) digital colour camera and a laser range finder. The multi-element antenna can be either mounted on a range-pole or on a pole fitted to the bum bag. The data collector, antenna, compass and laser range finder can all be fitted to a mono-pole as shown in Figure 6.

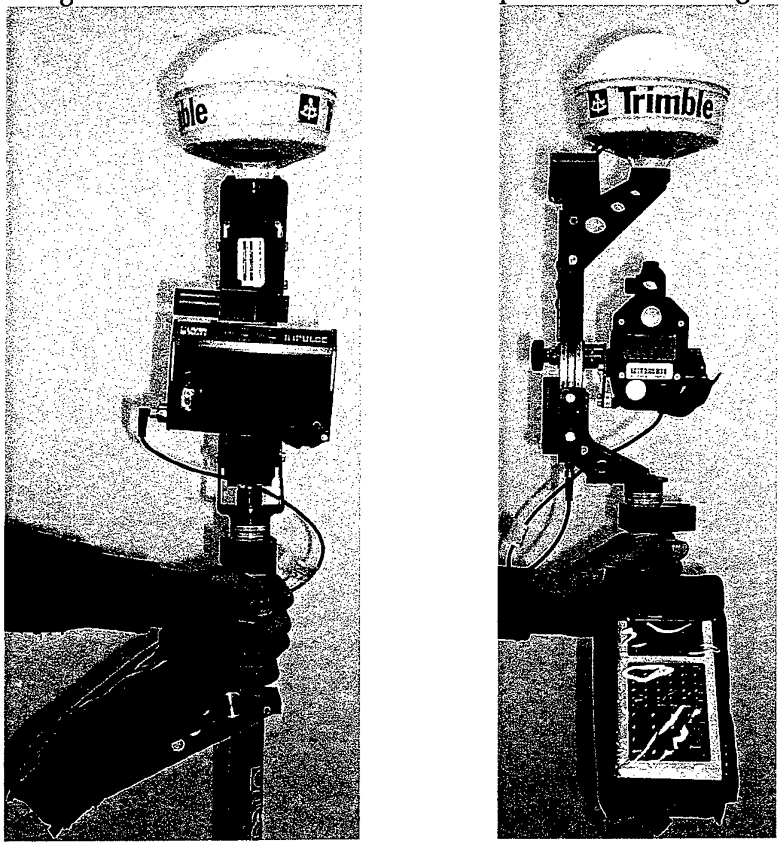

Figure 6. The equipment mounted on a monopole. From the top, the GPS and Beacon antenna, compass module, laser range finder (attached to the middle of the compass module and the data collector. The GPS receiver and most of the cable are not shown.

To use the system, an operator physically walks around the accident site, plots the position of the wreckage using the GPS (position corrected by data received via the correction receiver) and records the details on the data collector. Digital photos of individual items are taken at the same time. The position data, and the notes entered in the field (as attributes of the feature), are down loaded to a laptop at the site along with the digital photos. The data and photos are combined within GIS software so that notes, positions and photos of a particular piece of wreckage can be retrieved by querying points plotted on the wreckage map generated.

With the maps this system generates it is also possible to use either the laptop or the data logger, connected to the GPS to navigate back to the item selected. This allows re-inspection of any item or features requiring further examination to that in the initial wreckage analysis. Possible uses of this navigation facility may include a re-examination of a ground mark's width, depth, or wreckage orientation, or simply as a method for finding the wreckage that has been marked for further laboratory examination. This may be particularly important where consideration of the data produced leads to questions being asked about wreckage for which data was not collected at the time of the initial wreckage mapping. It may also be an advantage where parts are hard to find such as in long grass or dense scrub.

5.2 Required system specification

The system was required to allow the investigator to log the location of a piece of wreckage, ground/vegetation mark and/or a significant topographical feature to within 1m 2dRMS.

The system was divided into two units:

1. Field equipment

   A rugged portable system capable of taking digital images of features of interest, and a data logging system capable of logging a description of the observation along with the location. The GPS data were to be corrected in real time. The system had to be easily carried in the field and be suitable for use throughout Australia (as a minimum) ie. the correction service was to be available Australia wide.
2. Software

   The software was to be capable of integrating the photographic images along with the description and location data into a single GIS database. The software was to be able to recall Computer Aided Design (CAD) files (for identification) of the components and integrate these files into the GIS. The software was to be able to show only selected items ie. tailplane or wing wreckage parts, on an electronic map of the site. The software was to be able to accept scanned or digital maps, and include them in the GIS. The GIS was to have comprehensive search facilities including keyword or phase searching, which may relate to images, location, part No., description etc inputs. The software was to be interactive ie the investigator can select a logged location on the electronic map and recall the image, or notes, or a CAD file or any combination, in order to aid the analysis of the accident. The database was to be able to store up to 5000 pieces of wreckage (either internally or on removable media). The system was to run under Windows 95 and WindowsNT.

The system was envisaged to consist of a GPS field unit with realtime satellite correction data, a 24 bit colour digital camera - resolution better than 1500 x 1000 pixel and a portable colour PC equipment with software and database program able to link the location, notes and image information. The following were the requirements of the system components:

1. A portable GPS unit including an omnidirectional antenna and data logger with the following capabilities:

   Designed for field use, being splash proof, dust proof and shock resistant.
   Operate in the temperature range: -10°C to +50°C
   Have a minimum of eight channels.
   Contain a minium of 4MB of RAM for data logging.
   Be compatible with laser rangefinders and other electronic sensors.
   Have NMEA output and RTCM input.
   Include rechargeable batteries, which provide 8 hours field use as a minimum.
   Be supplied with a battery charger and AC power supply.

2. A correction receiver for the production of real time GPS correction, with the following capabilities:
    - The receiver was to be capable of operating in the temperature range: -10°C to +50°C.
    - The receiver was to be compatible with the GPS unit and its software.
    - It will be able to receive correction data over the entire continent of Australia.
3. Medium resolution digital camera, with the following capabilities:
    - Ability to store 50 or more images.
    - Greater than 1500 x 1000 pixel resolution at 24 bit (minimum) colour
    - High speed connections for both Wintel and Mac machines.
    - The ability to zoom from 1 to 3 times.
    - Down load images in a standard format.
    - Should be able to operate tethered to the selected computer.
    - Battery life, from a single charge, of 150 shots or greater.
    - Operate in the temperature range: -10°C to +50°C.
4. Colour notebook computer:
    - Pentium 166Mhz processor or faster.
    - Minimum of 64M byte RAM.
    - 1G byte (or greater) hard disc, preferably removable.
    - 10x (or faster) CDROM.
    - 12 inch (or larger) active matrix display.
    - 2 or more Type 2 PCMCIA inputs.
    - 28.8k (or faster) Modem.
    - 2M (or more) VRAM.
    - Lithium ion long life battery.
    - SCSI input or adaptor for SCSI to PCMCIA.
    - Loaded with Windows 95 or Windows NT.
5. Software packages supplied with the GPS and the GIS package should be capable of user configuration and be able to:
    - Output the data from the data logger to the GIS package.
    - Input of Geoid files into the GIS package.
    - Produce maps from the collected data, and allow integration of other maps, images and database inputs.
    - Allow cataloguing and keyword searching of the database produced with the GIS package.
    - Operate the GPS data logger.

5.3 The GPS receiver and correction service

The chosen receiver was a Trimble Pro XRS. This 12-channel DGPS (D for differentially corrected) receiver has specialised multipath rejection technology and atmospheric noise reduction techniques built in. It uses the Ll CA code with carrier-phase filtering and can calculate instantaneous full-wavelength carrier-phase measurements. The unit includes a differential GPS satellite receiver module and MSK (Minimum Shift Keying signal modulation) beacon receiver module, packaged within the single, weather proof housing.

The MSK beacon configuration contains a fully automatic dual channel MSK radiobeacon receiver for receiving differential correction broadcasts conforming to the IALA (International Association of Lighthouse Authorities) standard.

This DGPS supports multiple differential correction services. Flexibility in choosing a source for real-time differential corrections is achieved by having GPS MSK beacon and satellite differential correction receivers in the one box. All receivers use a single antenna, which contains multiple elements. Along the coastal regions of Australia, the MSK differential correction services can be used at no cost to the user. This service may extend about 100km inland depending on topography and atmospherics. For wide area coverage a base station will need to be setup near to the site of interest or a subscription to a satellite differential correction service will be required.

Submeter accuracy: typically less than 50 cm 2dRMS is possible with the Pro XRS assuming; at least 5 satellites, PDOP less than 6, and corrections from a Trimble equipped base station with Trimble multipath rejection technology.

The unit will collect positions as well as velocity at a time interval as short as 1 second. Velocity computations incorporate carrier phase data for greater accuracy. Time to first position fix is typically less than 30 seconds.

The unit has two RS-232 serial ports for integration with data loggers, PC's and external sensors, such a laser range finder. Offsets from external sensors are calculated 'on-the-fly'.

The accuracy of the Pro XRS without real time, or post-processed correction is 100 meters (2dRMS). After differential correction, the horizontal accuracy of each position is better than 50 cm (RMS) + one part-per-million (ppm) times the distance between the base station and the rover. The vertical accuracy of each position is submeter +2 ppm times the distance between the base station and the rover. Using real-time corrections, the accuracy of each position can be as good as submeter, but is subject to degradation from a number of the operational conditions discussed earlier.

The correction service chosen is supplied by Fugro, which deploys a system called OmniSTAR. OmniSTAR is an International DGPS System being part of the Fugro global DGPS network. Base stations provide industry standard formatted corrections to Network Control Centres (NCCs) at strategic geographic locations, where the corrections are decoded, checked, and converted for transmission to an L band communications satellite.

The signals are received at the user's location by the users correction receiver and decoder. These signals are demodulated by the receiver, and are made available, after selection of the desired individual base stations data set, as corrections for use in the GPS.

The antennae locations at the base stations have been surveyed to an accuracy of a few centimetres, as they occupy space on well-established sites. The base stations are provided with power backup to local power supply.

High quality, twelve channel Trimble GPS receivers are used in the base stations. The receivers are set up to provide data every 0.6 seconds. Satellite elevation mask angles are set to 5 degrees to assure that all satellites in view are tracked by each station.

The data from all base stations arrive at the NCC, via leased telephone lines, and/or VSAT. This arrangement allows for a very high probability of having useable data from each site continuously available.

The principal feature of OmniSTAR is the way in which the signals are monitored for integrity and made reliable for the user 24 hours a day continuously.

The compressed data stream is uplinked to a satellite in geosynchronous orbit. At the satellite, the signal is converted to the L-band down link (frequency range about 1.5 GHz), and transmitted to earth. As each message is broadcast, it is saved in the computer's memory. Receivers at the NCC demodulate the return signal from the satellite and pass the received messages to the computer, where they are checked against the saved messages. If any message is corrupted in transit, or should there be a failure in the transmission or reception system, the NCC is notified.

The NCC in Australia is situated in Perth. Base stations are situated in Perth, Karratha, Darwin, Townsville, Brisbane, Melbourne, Adelaide, Kalgoorlie and Bathurst. In the region nearby Australia, Bali, Auckland and Dunedin, also have base stations. The Australian base stations are marked on a map of Australia shown in Figure 7, along with the 500km and 1000km ranges from these stations. Also marked on the Figure, are the major sites of ADF aircraft operations. These all fall within 500km of a base station, so that submeter accuracy should be possible in the most likely areas where ADF aircraft accidents may occur.

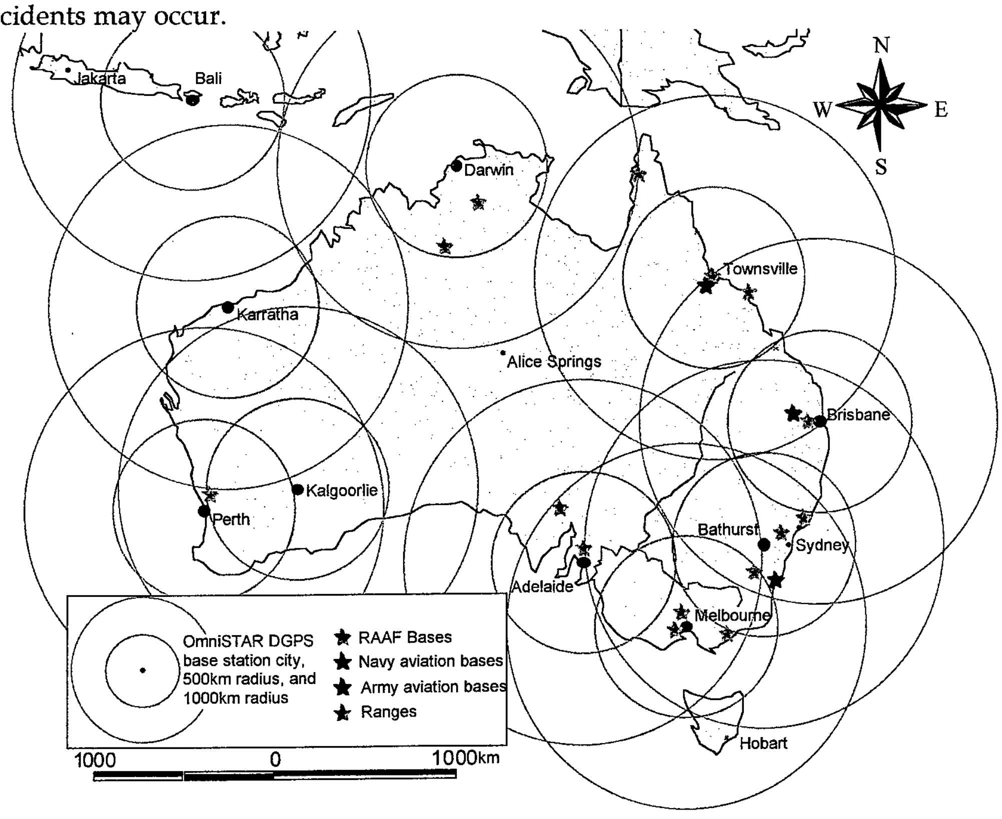

Figure 7 *The coverage of the differential correction service used by the AMRL GPS mapping system. Note that all major cities other than Alice Sprngs are close enough to a base station to allow an accuracy of better than 1m 2drms.*

Figure 8 shows two maps of the same wreckage - one without the differential correction and one corrected. As can be seen the system would not be suitable for wreckage mapping unless differential correction was available.

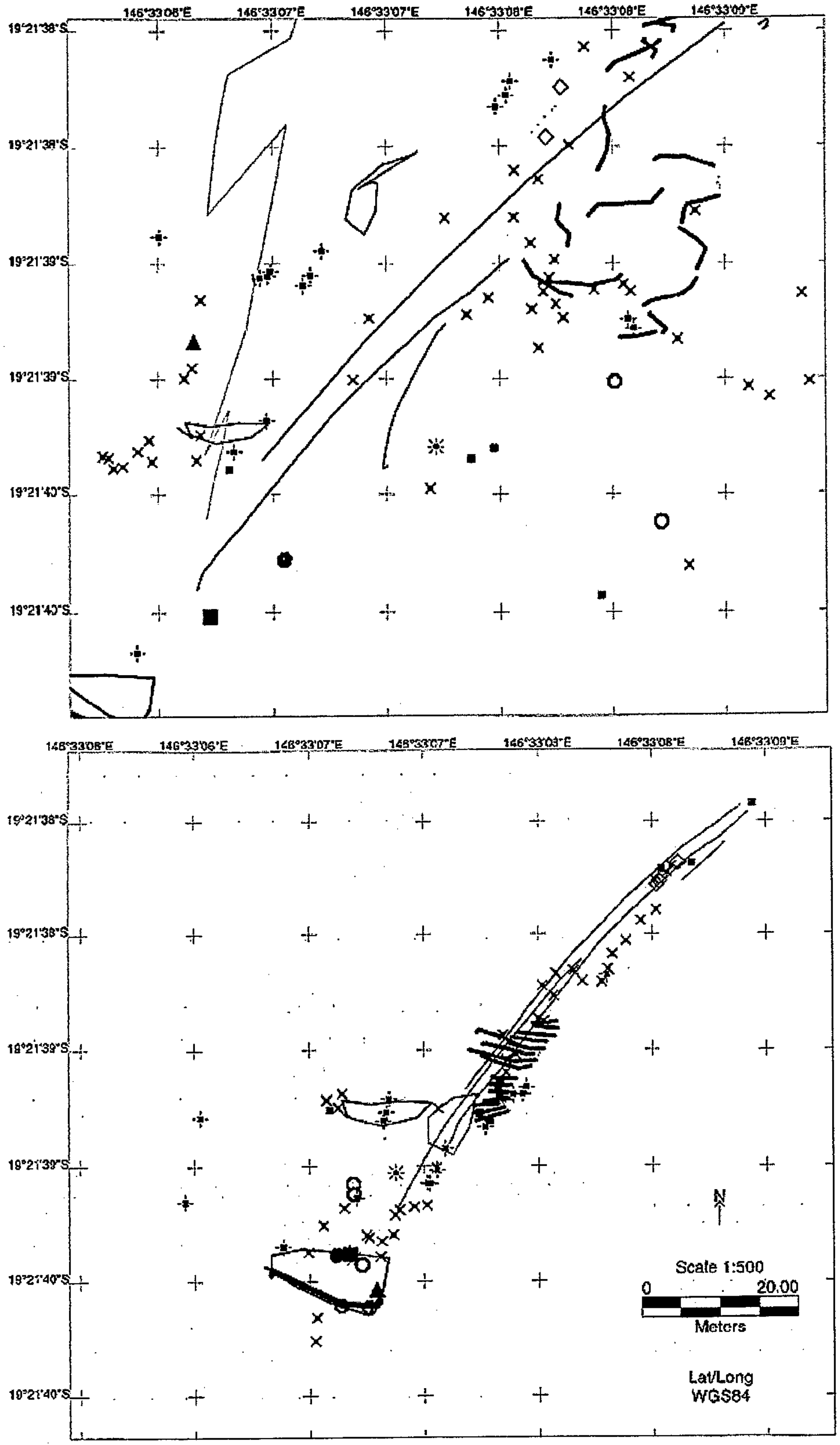

Figure 8. *Two maps of the same helicopter wreckage, at the same scale, the first without differential correction and the second corrected. Note the distortions of the positions (upper map), these are mostly caused by SA errors. The map shows, among other items, ground slash marks (brown lines) and skid marks (black lines).*

5.4 The GIS software

ArcView by Environmental Systems Research Institute (ESRI) Inc. was chosen for the AMRL system. While not the most powerful GIS available it has all the features, including expandability, that makes it easy to create maps and add data from areas such as GPS, maps, aircraft maintenance and digital image data. Using ArcView's visualisation tools, it is possible to access records from existing databases and display them on the maps created during an investigation.

ArcView GIS allows the production of publication-quality maps, presentations and fully interactive displays which can link charts, tables, drawings, photographs, and other files.

ArcView GIS software's built-in object-oriented scripting language, Avenue allows develop of custom tools, interfaces, and complete applications. In particular ArcView is supported in Australia by a large user base and a significant team of software support personnel. ESRI Australia, the suppliers of the software are also currently involved in the Army project PARARE.

ArcView GIS has the following features:

- Allows integration of charts, maps, tables, and graphics, with on-the-fly data updating.
- Can produce maps, of an investigation, at any scale.
- Allows several reporting capabilities.
- Numerous analysis capabilities.
- Allows the integration of images, CAD, map data, tables, and SQL databases.
- Contains easy-to-use labelling and text tools.
- A comprehensive developer environment.
- Can display maps in one of many supported projections.
- Create layouts that contain maps, tabular data, charts, and other graphics.
- Create grids, graticules, and legends for a layout with easy-to-use 'wizards'.
- Import and export standard format images such as TIFF, WMF, BMP, PICT, EPS, MrSID, and JPEG.
- Open image data from ADRG, BIL, BIP, BMP, BSQ, CADRG, CIB, EPS, ERDAS Imagine, GeoTIFF, GIF, JPEG, Landsat, NITF, PICT, RLC, TIFF (including TIFF 6.0), USGS DOQ, SPOT, and Sun Raster.
- Will perform spatial queries.
- Select features on one map based on features in another map.
- Join tabular data based on the location of features in a map.
- Overlay levels of data to create new data.
- Aggregate your data together building new information.
- Create new buttons, menus, tools and custom applications.
- Integrate other applications using DLL, RPC, and DDE.
- Edit tabular data and geographic features.
- Read map data directly from shapefiles, ARC/INFO, PC ARC/INFO, ArcCAD, AutoCAD (DXF and DWG), and Intergraph (DGN).
- Directly import map data from MapInfo, Atlas GIS, and ASCII.
- Use database tables directly from ASCII, dBASE, INFO, ACCESS, Oracle, FoxBase, SQL Server, Sybase, Paradox, DB2, Ingres, and any ODBC/SQL compliant database.
- Geocode with any supported maps data or database.
- CAD Reader extension provides direct support for AutoCAD (DWG and DXF) and MicroStation (DGN) files

- VPF Viewer extension provides a direct read from Vector Product Format (VPF) data and supports 2D and 3D VPF files
- Image Reader extensions support ADRG, CADRD, CIB, IMAGINE, JPEG (JFIF), MrSID, NITF, and TIFF 6.0 formats

Some of the other modules that can be added to ArcView include:

- ArcView Spatial Analyst extension; adds advanced spatial analysis and data manipulation
- ArcView 3D Analyst extension; provides the tools to create, analyse, and display 3D surface data
- ArcView Internet Map Server extension; enables you to put live mapping and GIS applications on the Web without any programming
- ArcView Tracking Analyst extension; enables real-time data display, capture, and playback.

A sample of a map produced with ArcView is shown in Figure 9. Although ArcView comes with a great deal of functionality, the initial assessments of its capabilities indicate that some functions will need to be added and others modified to simplify the task of mapping, correlating and analysing accident investigation data. Some of these functions can be added with other programs, and other functions will need software construction or modification. Some functions have been added by ESRI Australia, and further modifications are being sought.

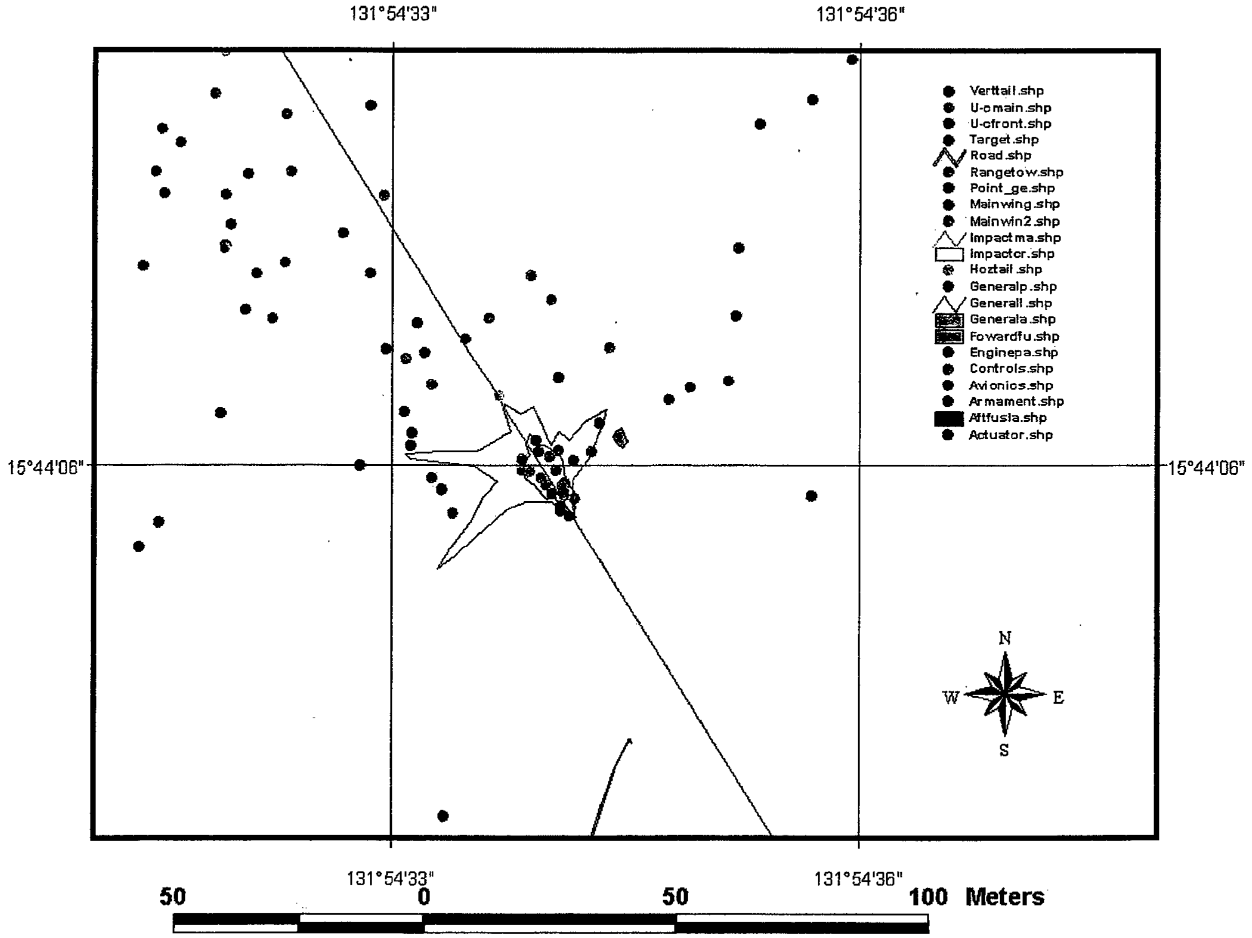

Figure 9. A Map showing an impact crater and several types of wreckage. This was produced during the investigation of an aircraft incident in Northern Territory.

5.5 Digital camera

Although several cameras were trialed with the system, all had resolutions around 1.5m pixel and all used a single colour masked chip. Each had problems with either clarity of images, ease of use, weight, batteries, size, lens options or price. For instance, one camera had a poor viewfinder and a flimsy plug for the downloading cable. It also had a fixed memory, which did not allow more than 60 pictures to be taken before downloading was necessary. On the plus side it stored the images as uncompressed TIFFs, thus preventing losses in a compression process, and it used a fast SCSI interface to down-load images. Another camera had a good viewfinder, removable memory chips and several download options. Unfortunately, the images were compressed resulting in losses in image clarity and enhancement possibilities. A SLR digital camera with interchangeable lenses was assessed and found to produce good lossless images, unfortunately this camera was twice as heavy as the other cameras and over twice the price. Since a camera was required with this system, a compromise was arrived at, and purchased. An example of an image taken with this camera is shown in Figure 10 (the resolution has been reduced to save space in this report). This unit will not be further described here, except to point out the images in this report were taken with the camera. Although there are still problems with digital cameras, they are improving in capability and cost so rapidly that the instrument purchased with the AMRL system is probable already out of date.

Figure 10. A sample image taken with the chosen digital camera of the GPS system being used at an accident site.

5.6 Laser range finder

To obtain automatic offset information for inclusion in the data collection phase of a wreckage survey a laser range finder was a latter purchase. The unit selected has an integrated inclinometer and compass module, and is capable of sending data directly to the data collector, which automatically applies the offsets to the data point being collected.

The laser chosen was a reflectorless Impulse 200, with an electronic fluxgate MapStar compass module. Both modules were manufactured by Laser Technology Inc. This laser has an internal inclinometer with a separate compass module, which fully integrates its readings with the results from the range finder and inclinometer. The Impulse 200 consists of a laser range sensor, a fluid tilt sensor, a sighting scope, and a data output port. The sensors are integrated with software controls and accessed through the two 3-button panels on either side of the unit and a liquid crystal display (LCD) screen on the rear panel. The range sensor measures distance ('slope distance' or 'absolute' distance) and the fluid tilt sensor measures vertical angles, providing immediate access to distance and angular values. Distance is obtained by measuring the time of flight of short pulses of infared light. The unit has a broad spectrum of sensitivity and can work with both reflective and nonreflective targets. The tilt sensor measures vertical angles, which the Impulse 200 uses to calculate height and elevation and to determine horizontal distances. The tilt sensor is capable of taking full 360 degree angular measurements, which are displayed by the tilt sensor as ± 180 degrees. When level (laser beam parallel to ground) the instrument is at 0 degrees, and may be rotated up through +180 degrees, and down through -180 degrees.

The compass is positioned in a separate module, to prevent problems with tilt; the compass module attaches to a swivel mount on the laser so that the laser can be tilted independently to the compass. Compass calibration can be carried out on site allowing adaptation to changing magnetic environments. The compass data is passed to the laser and combined with the distance and inclination data to calculate the offset, where it can be displayed in several forms on the LCD. The horizontal distance, vertical distance and compass bearing are fed to the GPS data collector by cables, for inclusion in the GPS position calculation. The specifications for both modules are shown in Table 2.

Table 2. Laser range finder, inclinometer and compass specifications

Unit mass:	1.57kg (Laser 1kg, compass 0.57kg)
Maximum range;	575m
Range accuracy;	30mm to a white target at 50m, 1σ 50mm to a grey target at 150m, 1σ Minimum range resolution, 10mm.
Laser	Infra-red FDA class 1
Power	2x AA batteries for up to 20hrs operation
Inclination limits:	± 180°
Inclination accuracy:	± 0.1°
Compass accuracy:	± 0.3°
Compass reputability:	± 0.1°
Compass resolution:	0.1°
Power	2x AA batteries for up to 20hrs operation

This unit has many features, most of which will not be discussed here. The unit gives offsets in absolute distance to target, target magnetic and inclination bearing; vertical height above present position and horizontal distance to target are calculated from the absolute distance and inclination. The laser is able to receive returns from seemingly difficult to measure targets such as the leaves on trees, or overhead cables, allowing the measurement and mapping of features such as: tree slash marks, tree height and powerline height. The laser can be gated so that returns outside the ranges set by the user can be rejected. This allows the laser to be fired through glass or scattered trees and still measure the distance to the target. For difficult targets, a reflector can be used.

6. Summary and Conclusions

At this stage, the equipment has been used at two accident sites with considerable success. Rapid production of maps has been achieved, which in one case very clearly aided the investigation of the accident.

Further development of the software is still required, to tailor it to the accident analysis task. When completed the software will allow the easy and rapid integration of data from many sources, the manipulation of that data to present it in the most useful manner and allow meaning full and manageable outputs of the data for reporting purposes.

Tests of the accuracy of the equipment have indicated that it is more than adequate for the accident investigation purpose. Some development of the field equipment is still required to reduce its weight and lengthen the period between battery changes.

7. Acknowledgements

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19. ABSTRACT
AMRL has developed a system to aid in the rapid mapping and the management of information gathered at aircraft accident and incident sites. This system is based on commercial mapping instrumentation which uses differentially corrected Global Positioning System (GPS) data, a medium-resolution digital camera and a geographical information system (GIS) software package. This paper introduces GPS, GIS and digital imaging, their use in the mapping and analysis of aircraft accidents, and a description of the AMRL equipment.