# SAFE SYMPOSIUM 2003

# SATELLITE AIDED SEARCH & RESCUE


## H R SMITH GROUP

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## INTRODUCTION

Over the past two decades, there has been a substantial increase in the use of satellite technology and services to enhance the world-wide flow of information and electronic data. Today, a wide range of different satellite constellations offer global communications capable of supporting military, commercial and private needs, including voice and data; navigation; weather forecasting; and SCADA (Supervisory Control and Data Acquisition) applications. These capabilities are provided either by constellations of multiple low earth orbiting satellites or by more distant configurations capable of providing continuous whole earth cover with as few as three operational satellites.

The use of satellites to enhance the effectiveness of Search and Rescue (SAR) operations has perhaps had the most significant impact in the field of personal safety and survival. Traditionally, SAR operations were mostly conducted using line-of-sight communications and homing systems which imposed significant operational constraints, particularly when faced with locating individuals in remote areas of the globe. The use of satellites to provide rapid global alerting and locating led to a transformation in search and rescue capability. Moreover, the proliferation of other satellite services, including GPS (Global Positioning System) and SATCOM (Satellite Communications), has provided further improvements in the effectiveness of SAR operations, and in the general safety of individuals in hazardous environments.

## AIM

The aim of this paper is to outline developments in satellite-aided Search and Rescue and to discuss some of the implications that this technology continues to have on the development of emergency beacons and transmitters.

## COSPAS-SARSAT – A GLOBAL APPROACH

Introduced in the mid-1980s, a global satellite search and rescue system (COSPAS-SARSAT) was 'launched' in a remarkable example of East-West co-operation by the USA, Canada, France and the former Soviet Union. Moreover, just one year before the fall of the Berlin Wall, the founder nations in 1988 signed the International COSPAS-SARSAT Programme Agreement which assured the long-term continuity of the system and availability of its services to all nations on a non-discriminatory basis. 'Launched' is perhaps a misleading descriptor because the COSPAS-SARSAT system comprises transceiver and processing packages embedded on a number of commercial satellites typically operating in the weather forecasting role. The co-ordinated implementation of a global SAR satellite system and supporting ground infrastructure was a very fine achievement, and one to which many owe their lives: 1,545 people in 2001 alone, and 14,292 people in total since its implementation.

## SATELLITE CONFIGURATIONS

**Low Earth Orbiting Satellites.** COSPAS-SARSAT now uses two different systems of satellites, although this was not the case initially. The system became operational with Low Earth Orbiting (LEO) satellites which maintain a height of about 600 miles above the Earth's surface with their orbits coinciding at the poles. At this altitude, a satellite has to travel at approximately 17,000 miles per hour to remain in orbit - any less and it would progressively loose altitude an fall to earth. Under these conditions, a LEO satellite takes approximately 100 minutes to complete one orbit, while to an observer on the ground, the satellite takes about 15 minutes to travel from horizon to horizon. Importantly, in low Earth orbit, a satellite is limited in terms of its visible horizon to an area of the Earth's surface measuring about 6,000 km in diameter. Consequently, one satellite would take around 12 hours to 'view' the Earth's entire surface. With four satellites however, this coverage time reduces to approximately one hour (termed 'Satellite Waiting Time') and it is for this reason that COSPAS-SARSAT endeavours always to keep a minimum of four LEO satellites operational at any one time.

**Geostationary Earth Orbiting Satellites.** Clearly to gain a wider view of the Earth, an orbiting satellite has to be further from the planet's surface. At a distance of 22,300 miles, not only is it possible to view a much larger area of the Earth's surface (theoretically +/- 80° latitude and longitude), but also one orbit uniquely takes 24 hours. Consequently, if the satellite is located directly above the Equator, a special condition arises where the satellite orbits in synchronism with the Earth's rotation with the result that the satellite appears in a fixed location above the Earth's surface. This condition is termed a Geostationary Earth Orbit (GEO). Significantly, with three GEO satellites, the whole of the Earth's surface can be continuously monitored within +/- 80° latitude. Moreover, in occupying a fixed location in relation to the Earth's surface, the satellite also appears at a fixed elevation which is overhead at the Equator, reducing to a maximum of 30 degrees in the UK for a satellite directly above the 0° Meridian. Actual elevation depends not only on the latitude of the observer but also on the relative longitude offset between observer and GEOS – effectively these criteria delineate the coverage of the GEO satellite.

**An Integrated Approach.** The use by COSPAS-SARSAT of both Low-Earth Orbiting (LEO) and Geostationary Earth Orbiting (GEO) satellites offers a number of benefits over a single constellation system. Firstly, by their relative motion with respect to the Earth's surface, LEOS can determine the position of a transmitting source (ie an emergency transmitter) on the Earth's surface by measuring the variation in Doppler shift as it over-flies the beacon. This important feature, combined with the LEOS' ability to cover (though not instantaneously) the whole Earth's surface, including the poles, makes an invaluable contribution to overall system capability. GEO satellites, on the other hand, provide virtually instantaneous cover for large areas of the globe, but excluding the extreme Polar regions. Moreover, only three satellites in geo-synchronous orbit are needed to monitor the Earth's entire circumference, thereby providing immediate detection of an activated beacon and eliminating satellite waiting time. In combination, therefore, COSPAS-SARSAT LEO and GEO satellite configurations bring together the benefits of both architectures in a unified and highly effective alerting and locating system for search and rescue operations.

## GROUND INFRASTRUCTURE

Clearly for the COSPAS-SARSAT system to function effectively, it is necessary to have a fully integrated supporting infrastructure capable of receiving and processing emergency transmissions, and alerting the appropriate Rescue Co-ordination Centre (RCC) from where the rescue can be initiated and directed. Emergency transmissions relayed via satellites are received through a worldwide network of Local User Terminals (LUTs) and passed first to Mission Control Centres (MCCs) for verification and action. Some 24 interlinked MCCs are responsible for processing and distributing alert data across the globe, and for tasking RCCs under their control for emergencies that lie within their area. MCCs are grouped into Data Distribution Regions (DDRs) and each DDR has a nodal MCC that acts as the focus for data distribution from its region to other DDRs. DDR's are thereby able to co-ordinate the rapid transfer of alert information to the responsible MCC so that, even if an emergency beacon is activated outside its national boundaries, the responsible MCC can be alerted and the most suitable RCC can be activated.

## FREQUENCIES & SIGNAL CONTENT

For many year's there were just two internationally agreed distress frequencies – 121.5 MHz (VHF) for civil users and 243 MHz (UHF) for (NATO) military users. These frequencies, and their associated swept tone modulation, provided a perfectly satisfactory means of signalling an emergency situation and providing a suitable terrestrial 'homing' source to assist SAR forces with the rescue mission. A major limitation of this method of communication was, however, that the signal contained no encoded information. It was therefore impossible either to identify the transmission source or to determine any other useful information that might aid the rescue mission. An activated emergency beacon would simply tell the local SAR authorities that someone, somewhere was in distress. Added to this, as many as 98% of all alerts on these frequencies continue to be false alarms which is highly inefficient and wasteful of resources when one considers that **all** alerts have to acted upon, at least initially.

**Impact of 406 MHz.** The introduction of COSPAS-SARSAT provided for the first time a means of digital data messaging which was to overcome many of the limitations associated with traditional distress frequencies. The chosen frequency was 406.025 MHz (notionally 406 MHz) and, unlike 121.5 and 243 MHz transmissions, comprised a short ½ second data burst transmitted at approximately one minute intervals. Not only did 406 MHz facilitate efficient satellite operation but it also provided a comprehensive means of conveying important data about the emergency. Typically, the data message identified the nationality and type of user (ie maritime, aviation or personal); it included a unique means of identification which allowed cross-referral to a national registration data base; and it provided other supplementary information which could assist the rescue effort. The message also made provision for inserting positional co-ordinates derived, for example, from an aircraft's Global Positioning System (GPS). Thus with the satellite system's dedicated 406 MHz frequency came a wide range of informational improvements that had not been possible using traditional distress frequencies. Such has been the proven success of 406 MHz, that growth of 406 MHz beacons is predicted to almost quadruple during the current decade. In turn, this has recently resulted in the introduction of an additional new operating frequency - 406.028 MHz - to accommodate future growth.

**Obsolescence Issues.** Obviously, the transition to 406 MHz could not be achieved overnight and consequently COSPAS-SARSAT had to provide a service on 121.5 MHz and, to a lesser extent on 243 MHz. However, satellite design constraints and the absence of data on these frequencies meant that 121.5 and 243 MHz beacons could never receive the level of service that was possible on 406 MHz. COSPAS-SARSAT nevertheless continues to offer a limited service on 121.5 / 243 MHz but this is available only via the LEO satellites, and therefore does not provide the immediate detection and identification available to 406 MHz users via the GEO satellites. More importantly, due to the high level of false alerts, and the need for rationalization, COSPAS-SARSAT intends to terminate the 121.5/243 MHz service by 2009. A transition to 406 MHz emergency transmitters by this time is therefore essential to retain a global SAR capability.

## MESSAGE PROTOCOLS

An essential requirement of the 406 MHz data message is that the information conforms to established and recognized formats or 'protocols'. These protocols fall into two main categories; namely, 'Location Protocols' and 'User Protocols'. The precise structure and application of these protocols is beyond the scope of this paper; however, it is important to note certain basic elements which these protocols contain: Firstly all message protocols must include specific coding that identifies the country of beacon registration and the type of protocol that is being used. In addition, 'short' and 'long' message options are available and this choice must also be coded into the message. A specific, and perhaps, obvious, characteristic of the 'Location' protocol group is that they contain position co-ordinates (latitude and longitude). Therefore, to support this protocol type, the emergency transmitter needs to be supplied with positional information usually from an external source, ie GPS latitude and longitude. In addition, all protocols include identification data which uniquely identifies the emergency transmitter by, for example, a dedicated serial number, aircraft operator / designator, or aircraft 21 bit address.

Because the various data protocols allocate different proportions of the message for position co-ordinates, the choice of protocol also affects the accuracy of positional data that is transmitted via the satellites. Typically, 'long message' Location Protocols offer the greatest accuracy (approximately 124 metres), while the short message versions of these protocols offer significantly different levels of accuracy; notionally, 28 km to 3.7 km. Finally, the User Location (long message) protocol offers an accuracy of approximately 7.4 km, while the User short message protocol has no provision for position information.

## SATELLLITE PROCESSING

Each LEO satellite is equipped with a SAR Repeater (SARR) which receives either 121.5 MHz (COSPAS satellites), or 121.5, 243 and 406 MHz (SARSAT satellites). The received signal is retransmitted after amplification through a 1,544.5 MHz downlink to the Local User Terminal (LUT). Most SARSAT satellites also carry a 406 MHz SAR Processor (SARP). Unlike the SARR, the SARP digital processor contains a memory module which allows message data to be time-tagged, stored and retransmitted when a LUT come into view.

**Local and Global Operation.** Because the LEOS SAR Repeater provides the only means of retransmitting emergency distress signals received on 121.5 and 243 MHz, the satellite must have simultaneous visibility of the emergency beacon and a Local User Terminal if the distress transmission is to be successfully received at the latter. The transmitting beacon must therefore be within a 3,000 km radius of the LUT which consequently limits the probability of detection on these frequencies. In contrast, when a SARP-equipped satellite receives a 406 MHz distress transmission, the processor stores this data and re-broadcasts the information to the first LUT that subsequently comes into view. These different modes of operation are called ‘Local’ (121.5 / 243 / 406 MHz) and Global’ (406 MHz) respectively.

**Detection Probability.** From the foregoing, it is clear that detection of an activated beacon by a LEO satellite is dependent on three significant factors: the location and time of beacon activation in relation to satellite orbits; the type of satellite that first detects the beacon (ie SARR or SARP), and the frequency of the emergency beacon. In addition, the latitude of the activated beacon also affects detection probability and waiting time because a greater degree or orbital overlap occurs at the poles than at the equator. The introduction of Geostationary Earth Orbiting Satellites (GEOS) therefore significantly improved the capability of COSPAS-SARSAT by enabling immediate detection and identification of 406 MHz beacons without the need for a LEO satellite to over-fly a beacon’s location.

## DOPPLER LOCATION

One overriding benefit of the Low earth Orbiting satellite, however, which could not be replicated by its geostationary counterpart, was the ability of the LEOS to measure the precise position of an activated beacon. This capability is due to the LEOS’ relative velocity with respect to the Earth’s surface and the consequent Doppler frequency shift that occurs as the satellite over-flies the transmitting beacon. The Doppler shift causes the received frequency effectively to increase as the satellite approaches the beacon’s position and to reduce as it passes overhead. The measured variation in frequency depends on the relative position of the beacon in relation to the satellite track and this variation tells the satellite the range of the beacon from its track at the Time of Closest Approach (TCA). This process does, however, result in ambiguity because the satellite cannot distinguish on which side of its track the beacon lies. Importantly, however, the frequency stability of 406 MHz beacons is sufficient for the satellites to use the effect of the Earth’s rotation on the measured Doppler variation to resolve this ambiguity in most cases. This is not the case, however, on 121.5 /243 MHz, and it is therefore usually necessary for a second satellite pass on these frequencies, if possible, supplemented by additional reports from other air/sea traffic to resolve the ambiguity. Thus it can be seen that the Doppler location process is significantly more reliable on 406 MHz than on 121.5 / 243 MHz. In addition, the higher frequency offers better Doppler resolution and, hence, greater position accuracy on 406 MHz.

## INTEGRATING GPS

One significant limitation of the COSPAS-SARSAT Doppler locating system is the time taken for LEOS to achieve an unambiguous position fix on an activated beacon. This so-called ‘Location Waiting Time’ can, in the worst case, approach 90 minutes which can be critical to a survivor in a hostile environment. Not surprisingly, therefore, satellite message protocols made early provision for the insertion of positional data into the 406 MHz message, initially so that Emergency Locator Transmitters (ELTs) installed on an aircraft might transmit position co-ordinates derived typically from on-board GPS. Position data was thereby immediately available to the rescue authorities via the GEO satellites. The challenge, however, was to incorporate a GPS capability within a portable Personal Locator Beacon, thereby offering the individual survivor the same probability of early location as that afforded to aircraft or ships in distress. The H R Smith Group therefore turned its efforts towards integrating a GPS antenna and receiver into a production 406 MHz Personal Locator Beacon (PLB) to allow precise latitude and longitude to be transmitted via the COSPAS-SARSAT GEOS to the appropriate rescue authorities – the resulting PLB now offers a 12-channel GPS receiver and 406MHZ capability, while also retaining its 121.5/243 MHz transmissions, including two-way speech. The PLB achieves a GPS position fix in less than 60 seconds from activation, and updates this information every 20 minutes.

## EMERGENCY TRANSMITTERS FOR AIRCRAFT

The introduction of COSPAS-SARSAT and 406 MHz emergency transmitters meant that aviation authorities responsible for safety soon decided that commercial aircraft should be equipped with emergency transmitters capable of operating on this frequency. The European Joint Aviation Authority (JAA) issued two 'JAR-OPS' directives, one for fixed wing aircraft and the other for rotary wing aircraft. These directives were complex and far-reaching, affecting not just newly registered aircraft, but also requiring retrospective action on existing fleets. Although generically termed Emergency Locator Transmitters (ELTs), the JAA and ICAO coined a number of different ELT types which where subsequently mandated for particular applications and routes. These ELT derivatives ranged from portable, manually activated devices - ELT (Survival) - to more comprehensive, automatically activated installations - ELT Automatic-Fixed (AF) and ELT Automatic-Portable (AP). In addition, for helicopters engaged hazardous operations over water the JAA mandated the carriage of ELTs Automatic Deployable (AD). A modular design approach was central to our being able to offer easily installed systems to meet the full range of ELT directives and requirements, and to provide in-built supportability, including built in test, diagnostics and message reprogramming functions.

## TORNADO ELT (TELT)

Perhaps the most demanding development task encountered to date has been the adaptation of ELT technology for military combat aircraft. Contracted about one year ago to develop an ELT system for the Tornado aircraft, the design and performance requirements of this combat system were far removed from the traditional specification for commercial applications. Firstly, the entire ELT had to be completely independent from other aircraft systems, while still supporting a 'location' protocol. This meant that the ELT had to incorporate an embedded GPS receiver capable of operating from the ELT's battery power supply when activated. Next, the ELT and its supporting services had to be built into a single, conformal, heat resistant unit, with integral antennas for the GPS receiver and ELT transmitter. Antenna design was a specific challenge – 243 MHz and 406 MHz elements had to be co-located in a cavity but still provide maximum polar coverage, and the GPS antenna was separately located beneath its own miniature circular radome. The whole unit is encased in a high temperature insulated moulding and radome. Lastly, the activation criteria specified by the JAA for commercial aircraft were plainly far from suitable for a modern combat aircraft; consequently, instrumented flight trials were necessary in order to optimize the ELT G-thresholds to prevent nuisance activations occurring during high-g manoeuvres, while also ensuring reliable operation in the event of a crash. The TELT development programme without doubt extended the boundaries of ELT design and will now provide a future basis for new-generation, stand-alone military-specified ELT systems capable of delivering GPS data with the minimum of aircraft integration cost. Moreover, the experience gained in developing the TELT will next be applied to developing a stand-alone commercial ELT system with integral GPS and a dual function antenna.

## EXPLOITING OTHER SATELLITE TECHNOLOGIES

Continuing developments in satellite-aided SAR equipment are aimed at improving the probability of early detection and location of individuals in an emergency. In some cases, however, individuals may be exposed to danger on a continuous basis, in which case an organization's duty of care may well extend to providing routine forms of position and health monitoring. Commercial satellites offer a range of services which include tracking and monitoring, and in many ways, the capabilities of these systems are not dissimilar to those which support search and rescue operations: namely, identification, locating, and monitoring. Indeed, the technologies are also becoming increasingly convergent and complementary. Consequently, we are exploring the feasibility of combining routine monitoring and emergency SAR functionality in a single unit. Common elements include GPS receiver, digital processing to create the necessary data message structures, and electrical power supplies, while different frequencies, satellites and message protocols would be employed depending on whether the unit was in its routine tracking or emergency mode.

In an emergency, the beacon would provide the full range of SAR alerting, data and voice communication on 121.5/243/406 MHz, while in its normal tracking mode, the beacon's emergency SAR function would be disabled and switched to a commercial satellite link using a special data module and transmitter to up-link information to the satellite network. LEO constellations comprising up to 66 orbiting satellites provide continuous global coverage and overcome the problem of satellite waiting associated with COSPAS-SARSAT LEOS. Therefore, regular position updates will be possible without the elevation operating restrictions associated with GEOS configurations. Ground connectivity with the data captured via satellite would be achieved using a base station satellite transceiver linked to PC hardware. In this way, the base station would have a dedicated broad-band satellite link to access tracking data which would be delivered in the form of 'wireless' electronic mail to a specified E-mail address. Such transceiver modules are now sufficiently lightweight and capable of being integrated with SAR beacon technology into a single package. Tracking data down-linked to a base station transceiver would be decoded and displayed on a dynamic electronic map display. Overall system latency (ie time between transmitting positional updates and displaying this data at the monitoring station) would be less than 5 seconds. The provision of satellite-aided tracking, coupled with integral emergency SAR functionality in a single unit, is a potential area of future development, and one that could have very significant benefits for those employed in hazardous exploration or training environments.

## CONCLUSION

Satellite-aided search and rescue has transformed the effectiveness of SAR operations worldwide. The combined use of an integrated network of low orbiting and geostationary satellites offers benefits of rapid detection and identification, together with Doppler location, thus allowing SAR forces to mount rescue missions with unparalleled efficiency and speed. Furthermore, complementary developments in 406 MHz emergency beacons and transmitters have ensured that the advantages of this global SAR system can be fully exploited to maximize human safety.

More recently, emergency beacons with integral GPS receivers have significantly improved the detection and location of individual users, While ELT systems for aircraft offer automatic activation and the ability to transmit position co-ordinates derived from on-board GPS. Importantly, 406 MHz ELTs are now mandated for carriage on all commercial airliners. Further development is being directed towards a fully integrated, automatic, stand-alone ELT system with integral GPS, including a military specified system for modern combat aircraft.

Such has been the pace of advancing satellite technology, that it is no longer necessary to restrict the process of locating and monitoring individuals to an emergency. By combining SAR beacon technology with other satellite capabilities, we expect soon to provide global monitoring and tracking together with emergency SAR functionality in a single portable unit. This possible future development could offer significant safety improvements for organizations that have a duty of care to safeguard individuals in hazardous pursuits and areas.

In sum, the H R Smith Group remains committed to the delivery of new and innovative Search and Rescue solutions and, in so doing, aims to be the best and natural choice for this vital and highly effective community.

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