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SatCom Today in Canada: Significant Research: Overview of the Cospas-Sarsat Satellite System for Search and Rescue

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Overview of the Cospas-Sarsat Satellite System for Search and Rescue

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ABSTRACT

Cospas-Sarsat, an international satellite system for search and rescue, started operating in 1982 and has been credited with saving thousands of lives since then. Hundreds of thousands of aviators, mariners and land users worldwide are equipped with Cospas-Sarsat distress beacons, which could help save their lives in emergency situations anywhere in the world.

This paper outlines the evolution of the system and describes how satellites are constantly circling the globe monitoring for 'SOS signals', while tracking stations on six continents receive the satellite signals, compute the locations of the distress events and forward the calls for help to the appropriate rescue authorities.

This humanitarian system is unique in the way that it is funded and operated, while its use remains free of charge to the end user in distress.

BACKGROUND

In the 1970s, light aircraft were carrying small, battery-operated radio transmitters that could be activated in an emergency distress situation. Such transmitters, called Emergency Locator Transmitters (ELTs), operating at the international distress frequency of 121.5 MHz, emitted a low-power signal that could be picked up by a receiver in another aircraft in the vicinity or in a nearby air traffic control tower. Some types of ELTs could be automatically activated by the impact of a crash to transmit the distress signal without human intervention. Marine vessels also started carrying similar distress beacons, called Emergency Position Indicating Radiobeacons (EPIRBs), which could float off a sinking ship and automatically emit a distress signal.

However, if a plane or ship went down in a remote area or in inclement weather, there might be no aircraft around to detect the distress signal for days or even weeks, which could be long after the distress beacon's batteries were depleted.

By the mid-1970s, more than 250,000 distress beacons were in service in Canada, Europe and the USA. Lives of aviators and mariners were being saved thanks to these transmitters, but there was still room for improvement, particularly as it was now the 'space age'.

A NEW SATELLITE SYSTEM

To improve the detection of such distress signals, particularly from remote areas, the concept of a satellite receiving system was proposed. In the mid-1970s, experiments were conducted in Canada, by the Communications Research Centre and the Department of National Defence, which used an amateur radio satellite, called OSCAR, to demonstrate the feasibility of using satellites for detecting and locating the source of distress signals. Similar experiments at NASA in the United States and the French Space Agency (CNES) further showed the technical viability of such a satellite system. These agencies agreed to set up a joint experiment for search and rescue satellite-aided tracking (SARSAT).

In 1979, the former USSR (and later Russia) agreed to join the experiment and develop a compatible system called COSPAS (a Russian acronym, Cosmicheskaya Sistyema Poiska Avarinyich Sudov, meaning a space system for the search of vessels in distress), and the Cospas-Sarsat System was born.

DEMONSTRATION AND EVALUATION PHASE

The development of an automated system to detect and locate very weak distress signals presented a formidable challenge. In the late 1970s and early 1980s, the design of the Cospas-Sarsat system was begun, radio frequencies were allocated, host satellites were arranged, search and rescue satellite payloads were designed and built and special ground receiving stations, called local user terminals (LUTs) were developed and installed. The world's first Cospas-Sarsat LUT was located in Ottawa, Canada.

The basic Cospas-Sarsat System [1] utilizes a constellation of four low-Earth-orbit (LEO) satellites in near-polar orbit, as depicted in Figure 1. With this type of orbit, a single satellite eventually scans the entire globe.

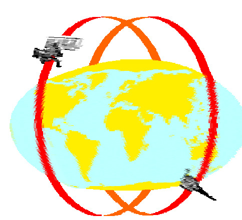

Figure 1: Cospas-Sarsat satellites in polar orbit.

However, there is a time delay because the global coverage is not continuous, due to the limited instantaneous field of view of a low-altitude satellite.

When the first satellite was launched in 1982 the ‘experiment’ was officially underway, and within days a real 121.5 MHz distress signal was detected. The ‘experimental system’ made headlines when all 3 people onboard a small aircraft were successfully rescued after their plane crashed in the mountains in a remote area of British Columbia, Canada. Their ELT distress signal was picked up by an overflying satellite and relayed to the ground station in Ottawa, some 4000km away, where the location of the distress was automatically computed. This information was sent to the search and rescue authorities and a rescue plane was soon on scene.

Even while the experiments were being conducted to assess the technical performance of the System, real distress signals were routinely being detected and every few days additional lives were being saved, thanks to the Cospas-Sarsat System. The first maritime rescue occurred soon after in the Atlantic Ocean, off the east coast of the USA.

In addition to providing distress alerting and locating services for the hundreds of thousands of existing owners of 121.5 MHz distress beacons, Cospas-Sarsat was also developing a new, more sophisticated, distress beacon operating at 406 MHz. This type of beacon allowed the distress location to be pinpointed more accurately and also transmitted a unique identification code. Search and rescue forces would then know where, as well as what, they were going to search for, making for a more effective mission.

At the outset, the demonstration and evaluation of the experimental Cospas-Sarsat System was scheduled to conclude in the mid-1980s, but the proven success of the system created enough demand for it to be continued, rather than being turned off. Since several other countries had also participated in the experiment and used the system to save lives, finding a way to transform it into an operational system was highly desirable. The four founding countries undertook to set up an official, worldwide System and declared the System operational in 1985.

FORMALIZING THE SYSTEM

In 1987, the Cospas-Sarsat Secretariat was established at the headquarters of the International Maritime Satellite Organization (Inmarsat) in London. In 1988, a formal intergovernmental agreement was signed, thus assuring the long-term continuity of the System, in which three United Nations agencies were also involved:

- the International Maritime Organization (IMO) for worldwide shipping,
- the International Civil Aviation Organization (ICAO) for worldwide aviation, and
- the International Telecommunication Union (ITU) for radio frequency allocations.

Participation by various other government bodies and industry was also initiated in order to get equipment standards adopted, new distress beacons type approved, manufactured and distributed to consumers, and more ground receiving stations installed around the world.

The System continued to expand with more countries sharing in its operation and use, more ground stations coming on line and more distress beacons being installed on ships and aircraft, resulting in more lives being saved every year thanks to the Cospas-Sarsat System.

In 1985, Cospas-Sarsat also started evaluating the use of geostationary-Earth-orbit (GEO) satellites as an enhancement to the polar-orbiting system to provide almost immediate alerts, with identification, for 406 MHz beacons. This topic is presented in greater detail in a related paper at IMSC ’99 (Demonstration and Evaluation of 406 MHz Geostationary Search and Rescue Systems), so is not described further in this paper.

PRINCIPLE OF OPERATION

System Concept

The basic concept of the Cospas-Sarsat System [1] is illustrated in Figure 2.

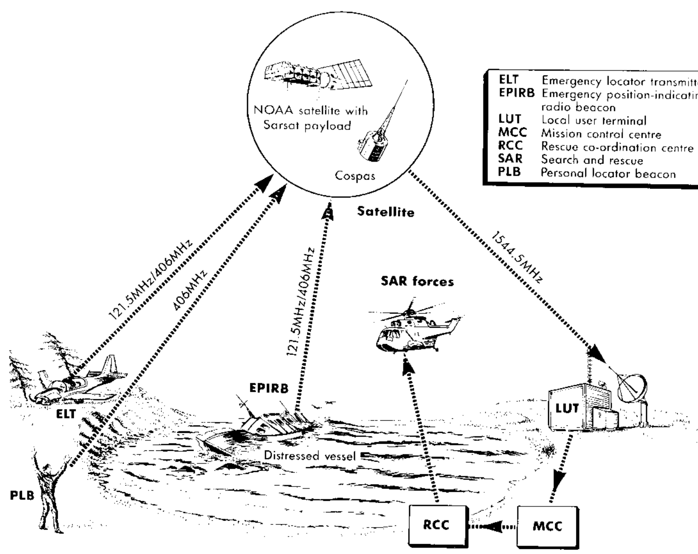

Figure 2: Basic Concept of the Cospas-Sarsat System

There are three types of radiobeacons: aviation ELTs, maritime EPIRBs and Personal Locator Beacons (PLBs). These beacons transmit signals that are detected by Cospas-Sarsat satellites equipped with suitable receivers. The signals are relayed to Cospas-Sarsat LUTs, which process the signals to determine the beacon location. Alerts are then relayed, together with location data, via a Mission

Control Centre (MCC), either to another MCC or to the appropriate Rescue Coordination Centre (RCC) or a Search and Rescue point of contact (SPOC) in that region.

Satellite Configuration

Figure 3 shows the path, or "orbital plane", of a satellite circling the earth around the poles. The satellite travels in this plane while the earth rotates underneath it, enabling a single satellite to eventually view the entire Earth's surface. At most, it takes only one-half rotation of the Earth (i.e. 12 hours) for any location to pass under the orbital plane.

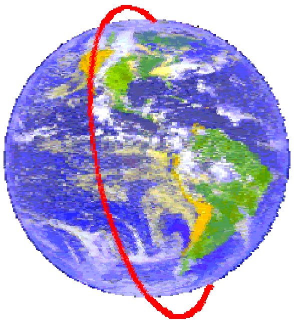

Figure 3: Orbital plane of a polar-orbiting satellite

With a second satellite, having an orbital plane at right angles to the first, only one quarter of a rotation is required, or 6 hours maximum. Similarly, as more satellites orbit the Earth in different planes, the waiting time is further reduced. The Cospas-Sarsat System design constellation is four satellites, which provide a typical waiting time of less than one hour at mid-latitudes.

Doppler Effect

Satellites at low altitude must move quickly over the Earth to stay in orbit. This movement causes a shift in the radio frequency called the "Doppler effect", as illustrated in Figure 4. Doppler location, using the relative motion between the satellite and the beacon, is the means used to locate these very simple devices. The resultant "Doppler curve" of frequency versus time has an inflection point when the satellite is at its time of closest approach (TCA) to the beacon.

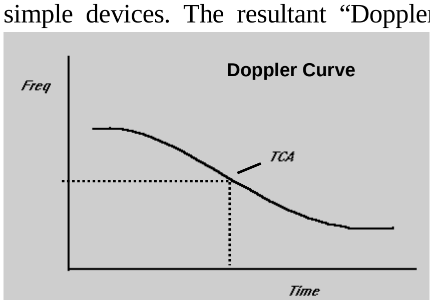

Figure 4: Doppler frequency shift versus time

Cospas-Sarsat selected low-altitude satellites in order to optimize Doppler performance and to be able to detect lower power distress beacons, while the near-polar orbit provides full global coverage, albeit with some time delay.

The Doppler calculation generates two possible positions for each beacon, the true position and its mirror image relative to the satellite ground track, as illustrated in Figure 5. This ambiguity in position can be resolved either by waiting for a second satellite pass or by calculations that take into account the Earth's rotation. On a subsequent satellite pass another pair of positions would be produced, but only one of those would overlap with one from the previous pass, thus establishing which is the true position of the beacon.

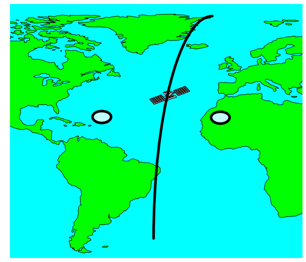

Figure 5: Two possible positions, one on each side of the satellite sub-track, result from Doppler positioning

With appropriate frequency stability, as specified for 406 MHz beacons, the true solution may be determined in a single satellite pass, because of the slight skewing of the Doppler curve due to the Earth's rotation during the 15-minute satellite pass. For 121.5 MHz beacons, normally a second satellite pass is required to resolve the ambiguity.

SYSTEM DESCRIPTION

The Cospas-Sarsat System comprises the space segment and the ground segment up to the point where the alert data leaves the MCC. The subsequent RCCs and SAR response units are existing national or regional entities, which utilize Cospas-Sarsat alert data to facilitate their operations. The distress beacons procured by the users are controlled on a national basis, and the 406 MHz beacons must be type approved by Cospas-Sarsat to ensure they meet the Cospas-Sarsat performance requirements.

Space Segment

The nominal System configuration comprises four satellites, two Cospas and two Sarsat, but often more than four are in operation, since older satellites, even when replaced by newly-launched satellites, continue to be used as long as they can provide some service.

Russia supplies two Cospas satellites, shown in Figure 6, placed in near-polar orbits at an 83° inclination at 1000 km altitude and equipped with SAR instrumentation at 121.5 MHz and 406 MHz.

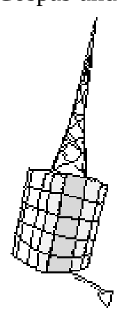

Figure 6: Cospas satellite

The USA supplies two multi-mission NOAA meteorological satellites, shown in Figure 7, placed in sun-synchronous, near-polar orbits at a 98° inclination at about 850 km altitude, and equipped with SAR instrumentation at 121.5 MHz and 406 MHz supplied by Canada and France.

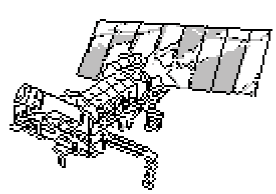

Figure 7: USA's NOAA satellite

A 243 MHz payload, onboard some of the satellites, operates in the same manner as the 121.5 MHz system, so is not further described in this paper. The 121.5 MHz payload is a repeater that retransmits all received signals in real-time, which is called the 'local mode' of operation. The 406 MHz payload repeats the band, as well as partially processes the received beacon signals, and retransmits them in real-time and also stores the digital data in satellite memory, which is continually replayed for several orbits to broadcast the data to all LUTs. This is called the 'global mode' of operation.

Each satellite makes a complete orbit of the earth around the poles in about 100 minutes, travelling at a velocity of 7 km per second. The satellite views a "swath" of the earth more than 4000 km wide as it circles the globe, giving an instantaneous "field of view" about the size of a continent. When viewed from the earth, the satellite crosses the sky in about 10 to 15 minutes, depending on the maximum elevation angle of the particular pass.

Distribution of Alert and Location Data

The alert and location data generated by LUTs are forwarded to appropriate SPOCs through the Cospas-Sarsat MCC network. Since a single distress incident is usually processed by several LUTs, in particular in the 406 MHz global mode of operation, the alert and location data are sorted by MCCs to avoid unnecessary transmission of identical data. The principle of continuous downlink transmission to all LUTs in visibility of a satellite allows simple downlink transmission procedures and provides a high level of redundancy in the ground processing system, both at 121.5 MHz within overlapping LUT coverage areas and at 406 MHz worldwide.

Distress Beacons

121.5 MHz beacons: It is estimated that there are now about 600,000 121.5 MHz beacons in use worldwide, primarily aboard aircraft, and are required to meet national specifications based on ICAO standards, which were not initially developed for a satellite system.

Such beacons, as illustrated in Figure 8, transmit only about a 0.05 to 0.1 Watt signal, having swept tone, amplitude modulation, which produces a warbling 'wow, wow, wow' sound in a nearby receiver. The carrier frequency of the beacon is not very stable and is significantly affected by the ambient temperature.

Figure 8: Typical 121.5 MHz ELTs used in aircraft

Therefore, the 121.5 MHz Cospas-Sarsat System was designed to serve the existing type of beacons, even though system performance would be constrained by their characteristics. Parameters such as System capacity (number of simultaneous transmissions in the field of view of the satellite which can be processed by LUTs) and location accuracy would be limited, and little or no information would be provided about the operator's identity. Even with these limitations, the efficiency of 121.5 MHz beacons has been greatly enhanced by the use of satellite detection and Doppler location techniques, and many lives have been saved.

406 MHz beacons: Development of a new generation of beacons transmitting at 406 MHz commenced at the beginning of the Cospas-Sarsat project. The 406 MHz units were designed specifically for satellite detection and Doppler location by having:

- high peak power output and low duty cycle;
- improved radio frequency stability;
- a unique identification code in each beacon;
- digital transmissions that could be stored in a satellite's memory; and
- spectrum dedicated by ITU solely for distress beacons

These parameters make the 406 MHz system superior to the older 121.5 MHz system by providing the following features:

- increased system capacity;
- improved ambiguity resolution and location accuracy (typically within 2 km versus 20 km for 121.5);
- identification of the user in distress;
- global coverage; and
- no interference from aircraft voice transmissions

Figure 9: Various models of 406 MHz distress beacons

406 MHz beacons, shown in Figure 9, transmit a 5-watt, half-second burst approximately every 50 seconds. The carrier frequency is phase-modulated with a digital message. The low duty cycle provides a multiple-access capability of more than 90 beacons operating simultaneously in view of a polar orbiting satellite, versus only about 10 for 121.5 MHz beacons.

An important feature of 406 MHz emergency beacons is the addition of a digitally encoded message, which provides such information as the country of origin and the identification of the vessel or aircraft in distress, and optionally, position data from onboard navigation equipment. An auxiliary homing transmitter is usually included in the 406 MHz beacon to enable SAR forces to home on the distress beacon.

There are now more than 20 manufacturers of 406 MHz beacons in 12 countries, and many more distributors around the world, with over 100 different models type-approved by Cospas-Sarsat [2]. The number of 406 MHz beacons in use has increased dramatically from virtually zero in 1985 to about 20,000 in 1990 and to more than 156,000 by 1998.

Ground Segment

Local User Terminals (LUTs): Cospas-Sarsat LUTs are ground stations which track the satellites, receive the distress beacon signals via the satellites, compute the locations of the distress signals and forward the alert data to Mission Control Centres. Most LUTs are fully automated; some of which are unmanned and installed in remote areas and can be operated remotely from the MCC. The LUT steers a tracking antenna to follow the satellite across the sky, so each LUT needs to know the satellite orbit data on an ongoing basis.

All commissioned LUTs meet the Cospas-Sarsat specifications, but the configuration and capabilities of some LUTs may vary to meet the specific requirements of the participating countries. The Cospas and Sarsat spacecraft downlink signal formats ensure interoperability between LUTs and the various spacecraft.

For the 121.5 MHz signals, each transmission is detected and the Doppler information calculated. A beacon position is then determined using these data.

Processing of 2400 bits per second digital data from the satellite (i.e. those generated from 406 MHz transmissions) is relatively straightforward since the Doppler frequency is measured and time-tagged on-board the satellite. All 406 MHz data received from the satellite memory on each pass is processed within a few minutes of pass completion.

At the end of 1997, 38 LUTs were operating on six continents, as shown in Figure 10.

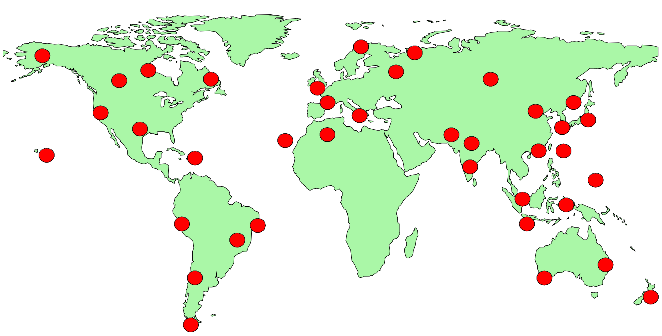

Figure 10: Locations of 38 Cospas-Sarsat LUTs in 1997

Mission Control Centres (MCCs): MCCs have been set up in most of those countries operating one or more LUTs. As depicted in Figure 11, an MCC is where distress alert data from the Cospas-Sarsat System is normally first viewed by a human, since most of the LUTs' receiving, processing and data forwarding systems are automated.

Figure 11: One of the Cospas-Sarsat MCCs (Canada)

The main functions of an MCC are to:

- collect, store and sort the data from LUTs and other MCCs;
- provide data exchange within the Cospas-Sarsat System; and
- distribute alert and location data to associated RCCs or SPOCs.

All MCCs in the System are interconnected through appropriate networks for the distribution of System information and alert data.

STATUS OF SYSTEM

Currently, some 30 countries are participating in Cospas-Sarsat [2], as shown in Figure 12.

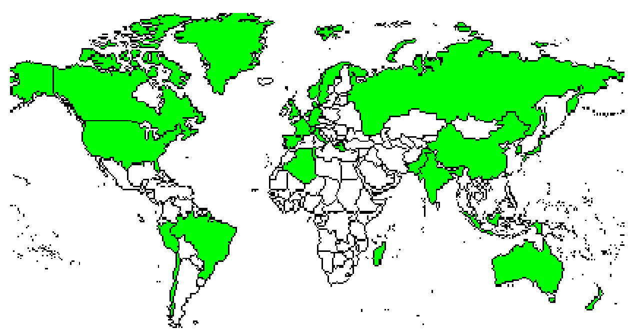

Figure 12: Cospas-Sarsat Participants (shaded areas)

The number of ground segment elements in the Cospas-Sarsat System [2] continues to grow, as shown in Table 1. (figures to 1999 were not yet available)

Table 1:Number of System Elements by 1998

Element	**Number**
121.5 MHz Beacons	600,000
406 MHz Beacons	156,000
MCCs	19
LUTs	38

In 1997, the Cospas-Sarsat System provided assistance in rescuing 1,312 persons, as shown in Table 2. (figures for 1998 will not be available until mid-1999)

Table 2: Summary of System Operations in 1997

Type of Distress	No. of SAR Events	No. of Persons Rescued
Aviation	76	186
Maritime	257	1,036
Land	56	90
Total	**389**	**1,312**

The 406 MHz system was used in 218 of these events (817 persons rescued) and the 121.5 MHz system was used in the other 171 SAR events.

Since its inception, the Cospas-Sarsat System provided assistance in rescuing 8,666 persons in 2,636 SAR events, from September 1982 to December 1997.

ADMINISTRATION AND FUNDING

The cost of implementing and operating the Cospas-Sarsat System is shared by the various member governments, while the distress beacons are paid for by the users. However, users do not pay to access the Cospas-Sarsat System. The four founding countries (Canada, France, Russia and USA) provide the space segment and they, as well as several other countries, installed and operate ground receiving stations and Mission Control Centres. The administrative costs of the Secretariat are shared by all member countries.

The estimated investment to date in Cospas-Sarsat equipment is approximately US$ 500,000,000, of which about half is for the system ($200M for satellite payloads and $50M for LUTs & MCCs) and half is for the distress beacons ($250M) purchased by the users

The program is managed by the Cospas-Sarsat Council, shown in Figure 13, comprising representatives of member governments, and is supported by a Secretariat, based in London, and a group of technical and operational experts (Joint Committee) which meets periodically.

Figure 13: A Cospas-Sarsat Council manages the Program

In 1990, Cospas-Sarsat was awarded the Seatrade Annual Award for Achievement, shown in Figure 14, for its contribution to safety at sea. The Cospas-Sarsat System is an integral part of the IMO's Global Maritime Distress and Safety System (GMDSS) for worldwide shipping, and is also recommended by ICAO for aviation.

Figure 14: Seatrade Award presented to Cospas-Sarsat

FUTURE

Even after more than 16 years of operation, the Cospas-Sarsat System continues to provide a valuable global service and is still expanding with new enhancements and more and more users.

The Cospas-Sarsat System is expected to continue providing service for many years to come, especially as thousands of users are mandated to carry distress beacons. The use of older 121.5 MHz beacons might diminish in the future as the more sophisticated 406 MHz beacons become commonplace, particularly with the addition of 406 MHz geostationary satellites and the inclusion of global positioning system (GPS) chips in some new beacons.

Inmarsat also provides a maritime EPIRB service for beacons operating at L-band. Other satellite systems coming on line in the near future will offer two way communications for persons in emergency situations, which will be very beneficial in many cases. However, these new systems will not likely have user terminals that would activate automatically in a distress situation and trigger a response by search and rescue authorities on a worldwide basis, and yet have no user charges. These new systems will be able to assist persons in distress, but none are foreseen to replace the Cospas-Sarsat System.

ACKNOWLEDGEMENTS

The author expresses appreciation to the Cospas-Sarsat Secretariat in London for the collection and compilation of the system data presented in this paper.

Additional information about Cospas-Sarsat can be obtained from the Secretariat's web site at:
www.cospas-sarsat.org/cospas-sarsat
and from national administrations in participating countries.

REFERENCES

[1] Introduction to Cospas-Sarsat, December, 1994
[2] Cospas-Sarsat System Data, February 1999