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# A FUTURE OF SATELLITE-AIDED SEARCH AND RESCUE

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## ABSTRACT

Satellite technology has been an integral part of maritime search and rescue since the Cospas-Sarsat system began operation in 1984. This system, credited with more than eighty-six hundred lives saved, has recently been augmented to provide immediate response through geostationary satellites. The other satellite-based distress alerting system, INMARSAT, launched its emergency Standard C service in 1991 and Standard E in 1997. Current plans call for a continuation of service from both of these vital systems at least through the first decade of the next century. We are currently witnessing the construction of a number of new satellite systems that will have the potential for revolutionizing mobile communications. These systems will be capable of emergency communication, and must be given due consideration in any look at the future. This paper reviews existing systems using satellites for distress alerting, describes the plans in place for them, and discusses likely developments.

## CURRENT SATELLITE-BASED SYSTEMS

### Cospas-Sarsat

Cospas-Sarsat uses instruments on U.S. meteorological and Russian navigation satellites in low (800-1000 km) polar orbits to relay signals received from emergency beacons anywhere on the Earth's surface to a worldwide network of tracking stations. The complement of resources in orbit varies over time, but the nominal constellation consists of Sarsat instruments on two U.S. satellites, and interoperable Cospas instruments on two Russian satellites. A varying Doppler frequency shift affects the signals received by the satellites during the satellite overpass, and the tracking stations analyze this shift to calculate the beacon locations.

*System Operation.* The system components and sequence of operation are depicted in Figure 1. The tracking stations, or Local User Terminals (LUTs), receive beacon information via the satellites and relay this to their associated Mission Control Centers (MCCs). The MCC, which may have multiple connected LUTs, generates alert messages based on all the information it receives, and sends these to the appropriate Rescue Coordination Center or Search and Rescue Point of Contact for response. After the first alert, information from additional satellite passes over the beacon is used by the MCC to refine the location estimate, and the updated location is passed on. As shown in Figure 2, there are today 38 Cospas-Sarsat LUTs in 21 countries. The U.S. operates the most extensive system, with six dual-antenna LUTs covering a band from west of Guam to east of Puerto Rico, plus Alaska. NOAA operates both the Sarsat satellites and the U.S. ground system.

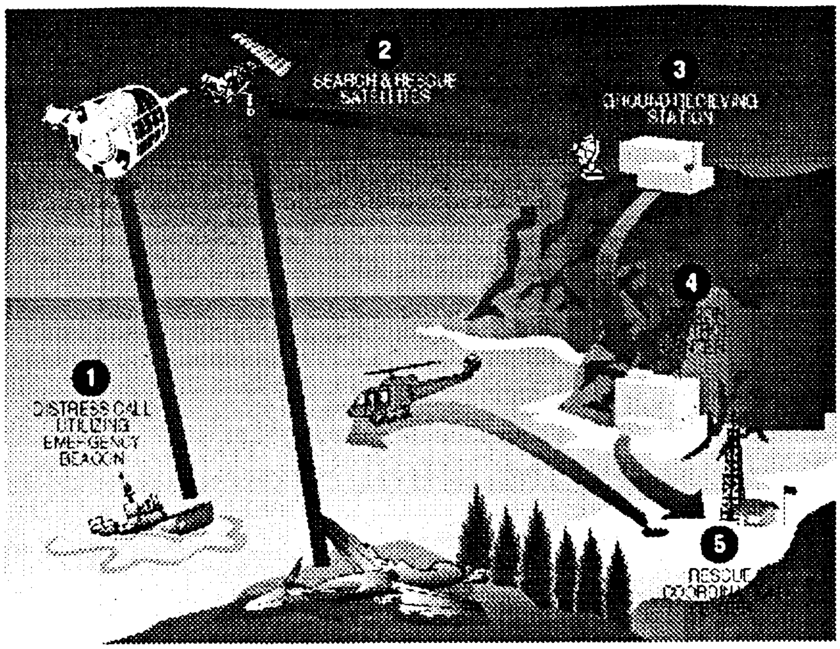
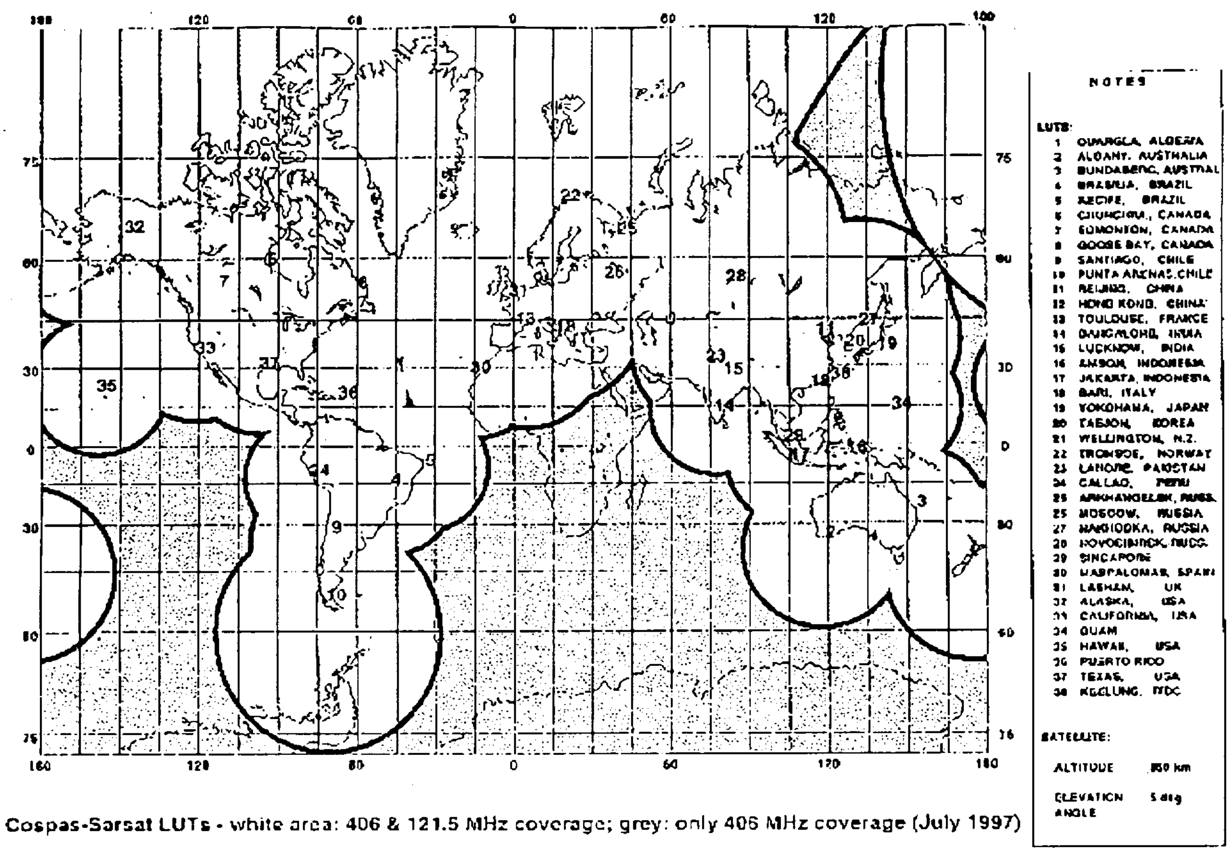



**Figure 1**. Cospas-Sarsat System Operation

The satellites carry two kinds of instruments - repeaters and processors. The repeaters, which operate in the 121.5 MHz band[1], receive beacon signals and retransmit them to ground stations in real time. The processors, which operate at 406 MHz, interpret the beacon transmissions received, reduce this interpretation to digital data, and send the data down to ground stations. The data is also stored in an onboard memory which is read out to ground stations at a later time. This ability of the processors to store and forward beacon data provides global coverage at 406 MHz, whereas beacons transmitting at 121.5 MHz must be near a ground station to be received through the satellite repeater. The tracking station locations thus limit the coverage of the system for 121.5 MHz beacons. (See Figure 2.) There are currently a sufficient number of tracking stations to provide 121.5 MHz coverage of approximately 60% of the Earth's surface.

*Emergency Beacons*. Beacons operating at 121.5 MHz have been in use since before the advent of Cospas-Sarsat. They were originally used to satisfy Congress's mandate in the early 1970s for Emergency Locator Transmitters (ELTs) in general aviation aircraft. They are still in wide use, although the original designs are being replaced gradually with models with upgraded performance and survivability. (Aircraft owners may optionally carry 406 MHz ELTs instead.) The Coast Guard authorized Emergency Position-Indicating Beacons (EPIRBs) that operated at 121.5 MHz in 1974. The total number of 121.5 MHz beacons in use in the world today is approximately 590,000

[1] Sarsat satellites also have repeaters operating in the 243 MHz and 406 MHz bands.




Cospas-Sarsat LUTs - white area: 406 & 121.5 MHz coverage; grey: only 406 MHz coverage (July 1997)

**Figure 2**. Cospas-Sarsat System Coverage

The 406 MHz beacons, of which there are about 135,000 in use, transmit digitally encoded identification information using a signal that allows a highly accurate frequency measurement. Registration data, keyed to the beacon identification codes, quickly provides search and rescue authorities with information necessary to carry out the initial research into an alert, and identifies the subject of the search if a search is required. With the accurate frequency measurements, a beacon's location can be determined (more than 90% of the time) to within 5 km. The corresponding location accuracy for 121.5 MHz beacons is 20 km. With both types of beacons, final pinpointing of the beacon is accomplished using aircraft equipped with radio direction finders, and the 406 MHz beacons include low-power 121.5 MHz homing transmitters to facilitate this.

*Geostationary Adjunct.* The Cospas-Sarsat system is augmented by repeaters on three geostationary satellites, operated by the U.S. (GOES) and India (INSAT), that relay 406 MHz beacon signals to the ground. These geostationary repeaters provide the advantage of near-immediate alerting over a very large area (approximately one-third of the Earth's surface for each satellite), whereas alerting via the low-orbiting satellites is delayed because it is necessary to wait after beacon activation for a satellite to pass within view. The geostationary relays provide little information about the location of the beacon, however, so their main function currently is to give the search and rescue forces a head start in responding to an alert. Deployment of search forces must usually await a location by a low-orbiter, but immediate response is possible if the whereabouts of the beacon's owner can be determined through contacts made via the registration database. A new type of beacon (discussed later) will transmit its own location along with its identification. These will give near-immediate alerting and location via the geostationary repeaters. The geostationary system is now concluding a demonstration and evaluation program and is expected to be declared operational late in 1998.

INMARSAT

INMARSAT, based on a constellation of five geostationary satellites, provides two kinds of emergency communication services. *Standard C* is a digital service with dual use. It handles routine message traffic to and from maritime and land terminals, and it carries special distress messages that can be sent from GMDSS-compliant shipboard terminals. The recently-inaugurated *Standard E* employs a unique L-band signal transmitted by EPIRBs and special ground terminal equipment at selected Coast Earth Stations to receive it. Geostationary satellites cannot use Doppler to locate emitters, so for both of these services location information is inserted into the transmitted message. This information comes from onboard navigation equipment for the Standard C terminals, and the EPIRBs carry their own GPS receivers. Distress messages received by INMARSAT are sent to specific Rescue Coordination Centers associated with Coast Earth Stations equipped for reception of EPIRB signals. Standard E service is available in all of the INMARSAT service areas, and most are covered by two Standard E equipped Coast Earth Stations.

## FUTURE OF THE CURRENT SYSTEMS

International agreement binds certain current satellite-based systems to provide the same basic services for many years to come. Those basic services are the ones that support the specified GMDSS protocols: reception and distribution of alerts from 406 MHz Cospas-Sarsat beacons, INMARSAT Standard C terminals, and INMARSAT Standard E beacons. (Note that 121.5 MHz beacon service is not included in GMDSS.) It is expected that INMARSAT will continue to offer the Standard C and Standard E services with no change into the foreseeable future. The remainder of this section will concentrate on Cospas-Sarsat.

*Sarsat Space Segment.* Plans for the Sarsat space segment parallel those for the two-satellite POES (Polar Orbiting Environmental Satellite) constellation, which is vital for measurement and prediction of weather conditions. A principle in the forward planning of this system has been that the search and rescue mission will continue to share the space platform that carries out the meteorological mission. Figure 3 shows the current projected launch sequence and schedule for the low-orbit meteorological spacecraft carrying the search and rescue packages. It should be noted that spacecraft are not launched unless there is a need to replace a failed one, and the on-orbit life of a satellite is quite variable. The projections must therefore be taken as approximate.

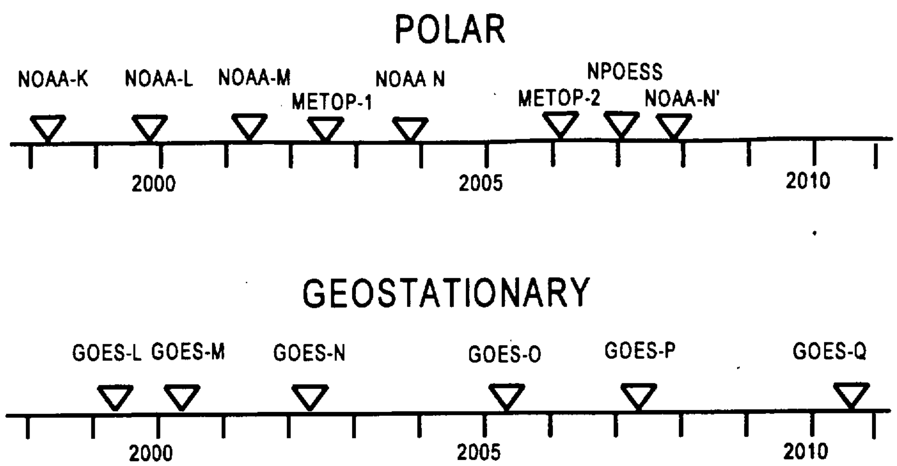



**Figure 3**. Planned Launches Supporting Search and Rescue

The current series of Sarsat spacecraft, designated NOAA, will conclude with NOAA N-prime, which is projected to be launched in 2007. After about 2002, there will be a mixture of NOAA, METOP and NPOESS satellites. METOP-1 and METOP-2 are meteorological satellites to be launched by the European Community. A new series of U.S. satellites that fulfill both the defense and the civil meteorological missions (called NPOESS for National Polar Operational Environmental Satellite System) will begin operation about 2007.

*Geostationary System Expansion.* Figure 3 also shows the plans for the Geostationary Operational Environmental Satellite (GOES) constellation, nominally consisting of two operational satellites and one on-orbit spare. These satellites will continue to carry 406 MHz repeaters. The European Space Agency is developing the second generation of the Meteosat series of geostationary meteorological imaging satellites. Current plans call for a Sarsat 406 MHz repeater to be included in the payload of that satellite. Russia plans to place 406 MHz repeaters aboard their Luch and Elektra communication satellites. Japan is considering carrying a repeater on a future GMS satellite. If most of these plans become reality, there should be near-global geostationary coverage (between plus and minus 75 degrees latitude) by about 2005.

*Cospas-Space Segment.* Russia has reiterated its commitment to maintaining the Cospas constellation in the forum of the Cospas-Sarsat Program.

*Cospas-Sarsat Ground Segment.* The coverage map presented as Figure 2 shows that there are now a sufficient number of LUTs to give multiple redundance in real-time coverage over much of the western hemisphere, and that coverage from at least one LUT extends over about 60% of the world. It is also clear that there are large areas without real-time coverage. These are mainly southern Africa and the Eastern Pacific. The installation of one or two LUTs in South Africa would go far toward filling the gaps, and there have been initiatives aimed at accomplishing this.

*Cospas-Sarsat 121.5 MHz Band Usage.* The future operational need for 121.5 MHz repeater service by the Cospas-Sarsat system has been a topic of discussion for several years. The use of satellite-generated alerts from signals in the 121.5 MHz band has always been made difficult by the high probability that an apparent emergency beacon signal is from an accidentally activated beacon or from a non-beacon source. Historically, only a very small percentage of 121.5 MHz alerts received via the Cospas-Sarsat system prove to be genuine. At the same time, the effort expended by rescue forces in investigating the many false alerts is high. Because of these reasons, and because there is a superior substitute readily available (i.e., 406 MHz beacons), it has been proposed in international fora that the use of emergency beacons operating in the 121.5 MHz band be discouraged, and that after a suitable period satellite surveillance of 121.5 MHz band be terminated. Both IMO and ICAO have supported this proposal in principle. Elimination of 121.5 MHz processing will have the effect of simplifying both on-orbit and ground resources. Hardware necessary for the repeater function could be removed from the satellite package, and the signal processing for the 121.5 MHz band could be eliminated in the LUTs.

*Location Protocol Beacons.* Near-term developments in Cospas-Sarsat beacons will probably center on the introduction of new beacons that make use of the ability to enter the beacon location into the beacon's message. This ability was granted recently by changes in the Cospas-Sarsat beacon specification that define new beacon message coding formats (the location protocols) that include latitude and longitude. The RTCM EPIRB Recommended Standard has been updated to reflect those changes. These self-locating beacons will be able to provide their locations immediately via the alert received through the geostationary repeater, ensuring a more rapid response. Two kinds of beacons are possible. They can contain their own navigation device (presumably a GPS receiver), or they can receive location information from an external device. In the latter case, a deployed beacon would always transmit the last location it received, whereas an EPIRB with its own GPS receiver would be able to provide updated locations as the beacon drifted. The Cospas-Sarsat ground system will be fully capable to make use of the beacon location information provided by these beacons in early 1999.

*LEO-GEO Processing.* The presence of a link from a beacon to two satellites - a Cospas-Sarsat satellite in low-Earth orbit (LEO) and a GOES in geostationary Earth orbit (GEO) - offers the possibility of alternative ground processing to improve system operation[2]. While the signals relayed by the geostationary satellites cannot in themselves be used to find the location (unless they are encoded with the location), the frequency of the signal received via GEO can be used as an additional data point in the Doppler location computation. This allows beacons to be located when there are not enough frequency measurements for normal Doppler location. When there are enough LEO frequency measurements, including the measurement from the geostationary relay increases the accuracy of the location estimate. This type of "LEO-GEO" processing is currently implemented in a ground terminal operated by the Canadian Department of National Defence. The statistics of the location solutions produced by this processing are now being collected and evaluated, and approval for operational use is expected.

*Other Platforms for Cospas-Sarsat Packages.* A drawback of the current arrangements for providing Cospas-Sarsat payloads is that the spacecraft carrying them are dedicated to other

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[2] B. Ghambir, R. Wallace, D. Affens and J. Bellantoni, "Improved Cospas-Sarsat locating with geostationary satellite data," IEEE Trans. Aerosp. & Electronic Systems, Vol. 32, No. 4, October 1996.

missions, and the failure of the search and rescue package is not sufficient cause to replace the satellite. This policy can result in periods when the on-orbit instrument complement is smaller than normal, causing the wait for a satellite overpass to be longer than normal. The chances of this happening would be reduced if there were more spacecraft carrying Cospas-Sarsat repeaters and processors. One intriguing possibility is for the GPS satellite constellation to carry a 406 MHz payload. The Block II F series of GPS spacecraft was designed with a significant amount of reserve payload space, consisting of unassigned volume, mass and electrical power to be used by an appropriate auxiliary payload to be specified. A search and rescue payload is an obvious candidate for this space. The Interagency Committee on Search and Rescue has proposed to the Air Force Space and Missile Command that this concept be studied, and preliminary efforts are underway to investigate the feasibility.

## POSSIBLE FUTURE SYSTEMS

The salient characteristic of the current systems that operate with emergency beacons is the ability to reliably receive messages from very small portable transmitters over a substantial portion of the Earth's surface. Iridium, Orbcomm and Globalstar are three satellite systems that will provide the same capability. These system, which are currently nearing completion, and similar planned systems operating in the Mobile Satellite Service (MSS), could represent a natural evolution of satellite-aided search and rescue support.

The Commercial Mobile Satellite System Working Group of the Interagency Committee on Search and Rescue has served as a forum to examine the issues involved in using commercial MSS systems in two distinct types of emergency applications - distress alerting and locating, and disaster response. The Working Group compiled a list of MSS system capabilities considered to be particularly desirable in these application areas. The status of this work was reported at a previous RTCM Assembly[3]. The Working Group has since then requested the various MSS system providers to describe the extent to which their systems have these capabilities, and is currently compiling the results. It is anticipated that the results of this work will be reported in a suitable forum in the near future. The following discussion has a more limited scope - it concerns issues central to the concept of emergency terminals, including ELTs and EBIRBs, that make use of MSS links.

### Operator-Attended MSS Devices

The communication devices that will be first offered by the new MSS system and service providers will be for general use. The voice terminals will look and operate like cellular phones. The messaging devices will have keypads and alphanumeric displays. Depending on the cost, these terminals may come to be used as a substitute for cellular telephone and marine VHF in coastal areas, and HF on the high seas. If their use becomes widespread, they will also undoubtably find use in emergencies because they will often be most readily at hand. But their effectiveness in emergencies will depend on the extent to which there is an infrastructure to

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[3] R. Wallace and B. Trudell, "Distress alerting and locating using the new mobile satellite services," RTCM Annual Assembly Meeting, May 1995.

quickly connect the user to the appropriate center for emergency response. Marine VHF, cellular systems, and HF, have this direct connection to emergency responders: VHF channel 16 is constantly monitored by the Coast Guard. Cellular systems honor "9-1-1" and many in coastal areas have short-cut dialing directly to the Coast Guard. MSS systems will need to provide the same type of emergency communication infrastructure. Because they are not locally connected like VHF and cellular, to be effective in an emergency communication capacity there will need to be a means for directing emergency calls on the basis of the caller's location. There is little indication that effort has been put into providing this.

Automatically-Activated MSS Devices

Even if MSS systems come to be used widely for general communications, and the infrastructure is provided to make them usable in emergency situations where there is an operator present, there will always be the need for "last-ditch" distress communication devices that activate automatically and do not need an operator to function (i.e., ELTs and EPIRBs). MSS systems designed to operate with hand-held terminals would clearly be capable of performing the basic functions required to support distress devices. That is, the relay of alerts sent from small globally-distributed devices, along with the device locations, to a central communication node.

Depending on market developments, it might be possible at some point in the future to produce self-activating emergency devices operating with MSS systems at a cost to the user that is lower than that of comparable devices using current systems. The dramatic decrease in the prices of VHF transceivers, GPS receivers and cellular telephones over the last several years is a direct result of high production volume. MSS terminals, if they become as popular as these other devices and their production volume becomes large, could become quite inexpensive. If that happens, it may be possible to incorporate the basic MSS terminal electronics modules into emergency terminals with the same features of ELTs and EPIRBs and sell them for substantially less than the Cospas-Sarsat or INMARSAT compatible devices currently in use.

Even with an economic motivation to create MSS-based EPIRBs and ELTs, there are challenges:

*Regulations*. Most carriers of emergency communication devices are required to carry them by regulation, and the equipment they carry is proscribed. Emergency devices based on MSS systems could only be used by the relatively small voluntary market unless the regulations were changed to allow MSS-based devices as substitutes for those currently mandated. This is a matter that would need to be taken up with IMO, ICAO and national regulatory bodies. Industry can be expected to press for this if there appears to be a sufficient market.

*Infrastructure*. This was mentioned earlier with respect to general purpose communication devices. To support distress terminals, MSS service providers would have to provide some means of quickly interpreting emergency messages and directing alerts to the appropriate rescue response facility based on the location. It has been proposed that alerts and locations from MSS systems could be sent to a Cospas-Sarsat Mission Control Center (in an appropriate compatible format) for handling. This sounds workable, but would require significant policy changes on the part of the MCC operator and the Cospas-Sarsat Program.

*Liability.* MSS service providers may not be willing to take the risk that they could be accused of negligence in a case where their system does not forward the alert as expected and lives are lost as a result. This is understandable for the new systems, considering that there is no operational experience on which to assess the magnitude of the risk. After a period of system operation confirms the expected reliability, service providers should be in a better position to decide whether to risk providing a life-saving service.

Hybrid Devices

Hybrid emergency devices, combining both the established emergency services and MSS, are also a possibility. The utility of a return link from the rescue forces to the emergency beacon, to acknowledge receipt of the distress message and confirm the existence of an emergency, has long been recognized[4]. A satellite-based paging system receiver incorporated into an emergency beacon could provide this return link. Acknowledgments and possibly other messages, originated by the Rescue Coordination Center responding to the alert, could be forwarded to the beacon via the satellite paging system operator by prior arrangement. The knowledge that the distress message has been received is vital information to the victims of the incident, and could even contribute to enhancing survival by enforcing the "will to live." This return link could also be used to pass instructions to the victims so they may assist in their rescue.

## CONCLUSION

The future of satellite-aided search and rescue is assured. The current systems will continue to work with improvements well into the future, and new or hybrid systems based on the technology of the new Mobile Satellite Services will very likely develop. The bottom line for the users of satellite-based emergency communications is lower cost and more reliable and responsive service.

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[4] F. Kissel, "Interactive distress beacon for Sarsat," RTCM Annual Assembly Meeting, April 1986