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SPACE SHUTTLE SEARCH AND RESCUE EXPERIMENT
USING SYNTHETIC APERTURE RADAR*

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ABSTRACT

Langley Research Center, NASA, is developing a concept for using a spaceborne synthetic aperture radar with passive reflectors for search and rescue applications. The feasibility of a synthetic aperture radar for search and rescue applications has been demonstrated with aircraft experiments. One experiment was conducted using the ERIM four-channel radar and several test sites in the Michigan area. In this test simple corner-reflector targets were successfully imaged. Results from this investigation were positive and indicate that the concept can be used to investigate new approaches focused on the development of a global search and rescue system. An orbital experiment to demonstrate the application of synthetic aperture radar to search and rescue is proposed using the space shuttle.

1. INTRODUCTION/BACKGROUND

A significant search and rescue effort is maintained through the world. U.S. Coast Guard statistics indicate, on the average for the 5 years (1970-1974), 72,000 sortie missions are conducted per year, resulting in saving 4,115 lives per year, and preventing the loss of \$235,570,000 in property per year. However, 1,496 lives are lost per year because timely rescue cannot be achieved [1]. These statistics expand when all search and rescue services are included. Future needs for these services are likely to increase as travel, trade, transportation, and recreation industries expand. Providing for this expanding service will continue to require the expenditures of considerable man-made and natural resources, and will necessitate risk-taking by rescue personnel. The development of a low-cost, low-risk search and rescue system tailored to meet this future growth and need must be a high priority endeavor.

Although current search and rescue efforts are extensive and are executed with dedication and diligence, there is no single system (technology) focused to meet the needs of a broad and expanding user community (aircraft, marine vessels, surface vehicles, and individuals). Search and rescue capability is inadequate and improvements are needed in the areas of: (1) global, all-weather, day or night operations, (2) timely detection of an emergency, (3) location of distress site, (4) identification of shortest path to rescue, and (5) low-cost user hardware.

* Contents of paper given in presentation at WESCON/76.

1.1 BASIC CONCEPT

A new search and rescue concept, originated at the Langley Research Center (NASA), is being pursued to develop needed technology improvements in the previously listed areas [2,3]. The concept (Fig. 1) embodies the use of passive RF reflectors in conjunction with an imaging or side-looking radar (synthetic aperture radar) to detect, identify, and locate the position of users exposed to emergency situations which may require search and rescue. Passive RF reflectors could be carried as standard emergency equipment by aircraft, ships, small boats, terrestrial vehicles, and individuals. The reflectors would be deployed in emergency situations to mark a distress site and to provide a radar target for subsequent detection and use in implementing search and rescue operations. The deployed target is detected and identified and the position is located by an Earth-pointing, Earth-orbiting, synthetic aperture radar maintaining a global scan. The radar provides an image in which the distress target and distress site are visible. In this way, surrounding terrain is mapped and can be analyzed to determine useful and practical ingress and egress routes as an aide in implementing rescue. The radar is operated within the 1- to 10-GHz frequency range. This frequency range is within a radio frequency window and in a frequency region of low RF background noise (Fig. 2); it provides for day or night and all-weather operational search capability.

In an operational system, a set of satellites would be maintained in a polar or near polar Earth orbit. Each satellite would be equipped with synthetic aperture radar and a communication system and would be operated in a search mode throughout successive flight passes over the global surface. Upon the detection of a user's distress target, image data would be generated and transmitted to a rescue operations control center where it would be used to initiate rescue operations. Distress targets would be carried by users and would be deployed in emergencies either by automatic and/or manual means. Targets would be designed to provide large radar backscatter cross sections (σ_t) over a wide range of aspect angles. See Eq. 1, where:

$$\sigma_t > \sigma_o \rho_a \rho_r \quad (1)$$

σ_o = terrain or clutter background radar cross-section density, m^2/m^2

ρ_a = minimum azimuth resolution, m

ρ_r = minimum range resolution, m

The basic concept allows the use of a number of RF reflector types, but the corner reflector is attractive for use as a search and rescue target. It is simple, effective, convenient to store and deploy, and low in cost. One interesting configuration can be fabricated from two basic components (Fig. 3): a Mylar-Saran (or similar nonconducting material) sphere and an internal array of corner reflectors. The reflectors are aluminized Mylar disks arranged into orthogonal planes and attached internally to the sphere. For deployment, the sphere is inflated with helium or hydrogen gas and is tethered by a line anchored at the distress site. This tethering places the target above local obstructions and provides a clear RF field of view for radar detection. In windy conditions, it may be beneficial to tether more than one target on a line to compensate for target motion.

Target deployment can be achieved in a number of ways depending on user needs. In general, these needs would translate into two basic deployment packages: a manual launch canister and a rocket launcher. Each configuration would include an RF reflector, an inflation device, a release mechanism, a tether line, a propulsion unit, and a packing and storage container. Specific targets would be selected and configured, packaged, and deployed as dictated by predetermined user class and expected operational constraints. For example, the target package for explorers and sportsmen would be simplified in comparison with the package designed for commercial airliners or large ships.

The following discussion offers a few examples which explore the basic concept and its practical applications. Once the system achieves target detection, it must be capable of uniquely identifying the detected signal within a processed image as a signal representing a search and rescue distress situation. Three identification approaches appear to be appropriate; that is, can be mechanized with an automaton and are thus suitable for an operational system.

One approach uses a single orbiting radar in conjunction with multiple targets. In this case, multiple targets are arranged in a known geometric configuration. An L-pattern or other configurations such as a linear, circular, or square array could be used. Target spacing would be maintained at three to five times the radar spatial resolution, and the pattern would appear in the radar image for use in recognition and identification. This approach lends itself well to the use of dual polarization radar and the use of digital difference processing to enhance detection.

In a second technique, multiple radars (two or three) would be operated at different transmission frequencies (X- and L- or L- and K_u -bands), would transmit at a single polarization (horizontal), and would receive both vertical and horizontal polarizations. A preselected set of frequencies (F_1 , F_2 , and F_3) and polarizations would be processed to generate three images. Different color filters and intensity levels would be assigned to each image and a composite (superimposed) image would be generated. In this way, false color enhancement is used to aid in target discrimination.

A third technique would employ a matched spatial filter. By using this technique, a single radar image is suitably recorded on film and is used as the input object in an optical processor. Coherent plane wave illumination is then used to transform the spatial variations of the radar image into its Fourier spectrum through a transform lens. Autocorrelation of the object spectrum with a stored matched filter of appropriate design may then be accomplished by performing a second Fourier transform of the light transmitted by the matched filter. At those points where correlation between the object spectrum and matched filter exist, a bright image spot providing the desired target identification is formed.

Once a target has been detected and identified, its position (longitude and latitude) can be determined from one of two basic measurements. One simple method would measure target reflector image position, within the total radar image, relative to any known ground reference point or points (deliberate man-made grid network targets or natural landmark imaged features) appearing in the total radar image. Then, when image scale factors and geographical position of the reference features are known, target location can be calculated. A second method would measure search and rescue target image coordinates within the total radar image relative to a fixed image frame coordinate position. This image coordinate can then be translated into Earth surface longitude and latitude as a function of radar geometry and orbital position (ephemeris data) at the time the radar image was recorded. The radar image is used to locate the position of the target; in addition, the target is imaged together with the natural localized terrain in which it is embedded.

2. SHUTTLE EXPERIMENT

The Space Transportation System (STS) development in progress will provide an unprecedented, timely, and low-cost opportunity to evaluate and demonstrate this search and rescue concept in the real space/Earth environment.

The long-range objective of this technology development experiment is to define and specify an operational low-cost user global search and rescue system structured to meet future demands.

Shorter-ranged objectives include: the development and testing of simple RF reflector user targets including emphasis on configuration, type, size, deployment, array configuration, long shelf life, and low-cost (a number of re-search reflectors are under development at NASA's LaRC - examples are shown in Figures 4 to 8); specification of radar relative to day-night all-weather operation, frequency selection, polarization, swath width, resolution, antenna, pulse repetition rate, pulse width, chirp modulation, RF power requirements, motion compensation, pointing, and onboard data recording requirements; analysis of data processing to optimize system performance - analysis of detection,

identification and location requirements and isolation of radar processing algorithms; parametric analysis of communication requirements to determine RF link characteristics needed for an operational system; specification of a shuttle experiment using global ground targets representative of the major terrain (background clutter) classes found on Earth; execution of aircraft flight testing leading to an supporting a shuttle flight test of the basic concept; and the step-by-step definition of an operational system in concert with ongoing development leading to a shuttle experiment. Data from the shuttle experiment is required to support trade studies to augment radar and processing technologies to minimize user hardware cost and complexity.

The technical objective of the shuttle test is to locate special target reflectors and display them together with an imaged terrain map. The utility, limitation, and accuracy of detecting, identifying, and positioning a variety of Earth-located passive reflector targets is to be determined. Also the utility of having surface-image data simultaneously provided with position data is to be demonstrated and evaluated. A comparison of imaging performance among multiple carrier frequencies will be made, and the utility of having wide and narrow swaths with coarse and fine resolutions will be determined.

Primary specifications of the radar for search and rescue applications are: (1) large area coverage mode with wide swath width and range resolution greater than 25 meters, (2) real-time or near real-time alarm when distress reflectors are detected, (3) direct link to rescue organization, (4) multi-wavelength, multi-polarization, and (5) limited swath width mode with resolution approximately 3 meters. A conceptual block diagram for the shuttle experiment search and rescue radar system is given in Figure 9.

Major design considerations for very wide swath capability in an imaging radar include: (1) ambiguity constraints, (2) antenna requirements, (3) transmitter power, (4) pulse synchronization, (5) data rate, and (6) recorder requirements. The system must be designed for multichannel operation. Very wide swath coverage can be realized with multichannel operation utilizing multi-beam antennas as illustrated in Figure 10. Dual swath coverage with overlap (if desired) as illustrated in Figure 11, provides very wide swath width and requires parallel channels for receiving and recording. Isolation between channels and use of a single transmitter can be realized by radiating different frequencies on alternated pulses.

Narrow swath width, fine resolution mode of operation can be obtained by combining the two feeds with signal phasing to illuminate the complete reflector structure. The fine elevation beamwidth will result in greater antenna gain with illumination over a narrow swath.

In an orbiting imaging radar the pulse repetition rate will be constrained by the range-azimuth ambiguity requirements, and transmit-receive isolation requirements. The former can be overcome, within limits, by antenna pattern design. Realizable isolation is independent of antenna pattern and will be determined by propagation delays over the mapped swath. General constraints on the pulse repetition rate can be derived for a given set of radar parameters. Use of dual (but closely spaced) frequency channels will give the capability to operate such subswath somewhat independently.

One operating frequency should be in the 15-18 GHz region. This frequency is a compromise between ambiguity response, atmospheric absorption, and maximum cross section realizable from a given corner reflector. A second lower frequency, 1-4 GHz region, and dual polarization should be included to provide multispectral information. This provides maximum interpretability for determining the nature or conditions of the rescue site (soil moisture, ground cover, etc.)

Problem areas requiring additional research and development include: (1) antenna development to achieve the optimum configuration for both dual beam (wide swath) and narrow beam (fine resolution narrow swath) in a single antenna structure, (2) antenna pointing: use of clutter lock system in the space shuttle radar, (3) basic navigation accuracy, (4) real-time signal and recognition processing, and (5) synchronization and pulse repetition rate controls to insure desired swath coverage.

The experiment is designed to operate with man in-the-loop while shuttle is maintained in orbit as depicted in Figure 12 over a 7- to 14-day duration

in a sortie mode of flight. At least 15 ground sites are selected on a global scale to provide targets in the major classes of terrain in which targets would be embedded. These terrains include oceans, seas, salt lakes, fresh water lakes, ice regions, mountains, tropical forest, desert and semi-desert regions, broad leaf and coniferous forests, grass lands, undifferentiated highlands, and tundra and ice caps [4]. Targets will be deployed at these selected sites and will be imaged on successive overpasses by the onboard shuttle radar. Primary radar signal data will be optically recorded onboard and will be returned after the mission for processing, analysis, and publication and dissemination of results. In addition to onboard data recording, selected image data will be transmitted over a shuttle-to-ground RF link to provide data needed to specify communications requirements for a future operational system. This experiment is being planned for a Shuttle/Spacelab [5] flight in early 1981. A full-scale Spacelab mockup is shown in Figure 13.

RESULTS TO DATE

A number of analytical studies were made and two airborne radar tests were completed - one in Florida in 1973 [3], and one in Michigan in 1975. These tests were designed to evaluate detection and identification. Objectives of the Michigan test were: (1) obtain multi-wavelength radar imagery of reflector configurations situated in various terrain types and (2) obtain radar imagery of different reflector types and configurations for use in recognition experiments. The area imaged during the demonstration flight is shown in Figure 14.

Data obtained from the Michigan test are being analyzed at LaRC and ERIM. For example, two images obtained at 3 cm wavelength, horizontal and vertical polarization, are shown in Figures 15 and 16 for the Temple test site (Site III). Ground site reflector layout is shown in Figure 17. The circular geometry array, the "L" array and the balloon reflectors can be seen on the imagery.

The Michigan data are being analyzed to develop the optimum procedure for the space shuttle test. Similar studies have been made using Florida test data and results are shown in References 3 and 6.

Radar cross-section measurements have been made (in the Environmental Research Institute of Michigan's anechoic chamber) using a number of different types of reflectors. Results obtained are compared with ideal reflectors and are summarized in Table 1. Measured radar cross-section values obtained for both balloons and erectable corner reflectors are less than ideal reflectors of identical dimensions due to construction tolerances.

The circular array used in the Michigan test is attractive for its angularly symmetric geometry. If an array of point scatterers is arranged in an angularly symmetric geometry of a known size, an automatic pattern recognition algorithm can be implemented which does not require an orientation or a size search. One intuitively satisfying geometry consists of a reflective ring with possibly a point reflector located at its center. This geometry is illustrated in Figure 18. This reflective ring would be ideal from an automatic pattern recognition viewpoint, but it would be very difficult to construct with point reflectors. The arrangement shown in Figure 18 represents a practical arrangement of point reflectors such as trihedral corner reflectors.

The signal-to-noise (actually signal-to-clutter) requirement is determined by the clutter characteristics, the desired detection statistics, and the details associated with the reflector array. For the example considered above, the greatest reduction in required signal-to-noise ratio was realized by going from a single reflector element to an array containing only a few elements, namely, seven. Going from 7 to 19 elements only reduced the radar cross-section requirements by approximately a factor of $1/4$ which corresponds to a reduction in corner reflector height by $1/\sqrt{2}$.

The circular array of reflectors is planned for use in the shuttle test; however, additional analysis will be conducted.

Results from aircraft tests and studies have demonstrated the feasibility of the basic concept. A number of inflatable, erectable, and rigid RF targets were developed and have been tested including simple corner reflectors, and radar requirements have been defined and are within the capabilities of today's technology. Both X-band (9.3 GHz) and L-band (1.165 GHz) radars (developed by ERIM [7]) were simultaneously used in testing. Each channel used

horizontal polarization for transmission and simultaneously received horizontal and vertical polarization energy reflected to the transmitting antenna. This provided simultaneous recording of four channels of radar imagery. Test images and data have been analyzed and used for conducting both analog and digital data processing studies. Processing results from this work demonstrate the value of digital difference imagery and false color enhancement algorithms relative to target identification.

Preliminary orbital requirements studies were completed and indicate a circular near polar orbit (inclination of 85.3°) of 470.22 km altitude is most suitable. This orbit is designed to provide total Earth surface coverage every 12.56 hours using three radar equipped satellites. Basic radar geometry to achieve this desirable, approximately 12-hour, coverage includes a swath width of 370 km and a maximum range depression angle of 45° .

Results to date indicate: (1) relatively small circular trihedral corner reflector targets (0.3 m to 0.6 m on edge) positioned in natural terrain, characteristic of many remote areas of the world, can be detected and identified using synthetic aperture radar; (2) radar returns are sensitive to transmitted signal polarization and frequency and this phenomena can be used to structure data processing (digital difference, false color enhancement, composites, and spatial filtering) suited to the unique identification of search and rescue targets; (3) the proper use of target arrays relative to geometry, size, and target types can enhance the identification process; (4) target spacing should be maintained within 1.5 to 2 times minimum radar resolution; (5) reflector target radar cross section should be equal to or greater than the product of minimum radar resolution and terrain background radar cross-section density; (6) it is advantageous to use at least two radars simultaneously having dual polarization receiving capability on each channel; (7) a near polar orbit of approximately 470 km is desirable; (8) depression angle should be about 45° ; and (9) swath width should be at least 370 km to achieve an approximate 12-hour, 100-percent Earth surface coverage. This wide swath-width requirement may be used for a coarse-look mode of operation and may be used in conjunction with a 59-km to 56-km fine-look mode of search.

Study of the basic concept and evaluation of results obtained from aircraft flight tests indicate a multiple frequency, dual polarization, day-night, all-weather, global search and rescue system is feasible. The next logical step is to test and demonstrate the concept in low-Earth orbit using the space shuttle, and work is in progress to carry what has been learned toward a shuttle technology demonstration test flight in early 1981.

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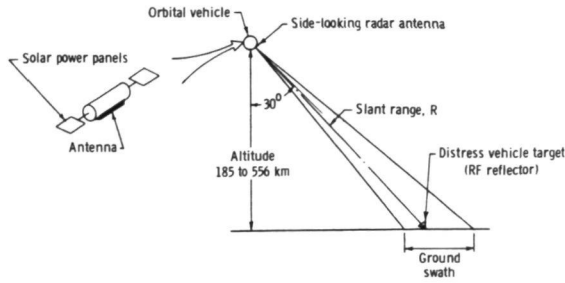


Fig. 1. Global search and rescue basic concept.

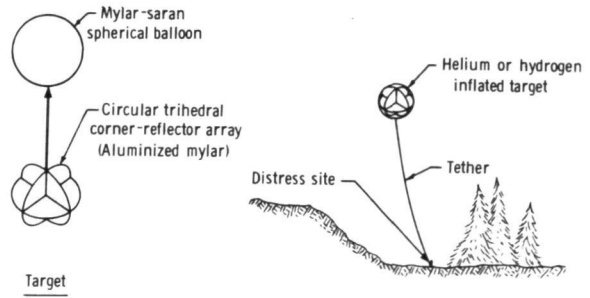


Fig. 3. Search and rescue reflector target concept.

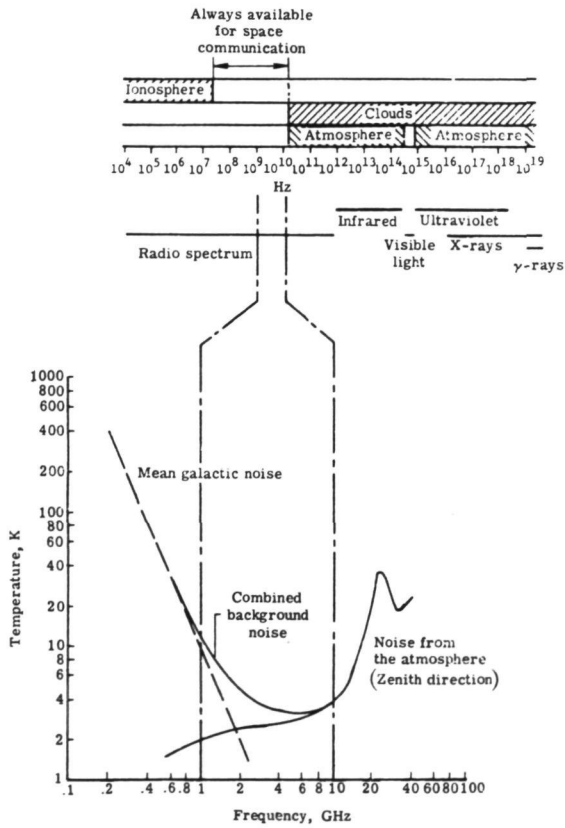


Fig. 2. Frequency window for search and rescue radar.

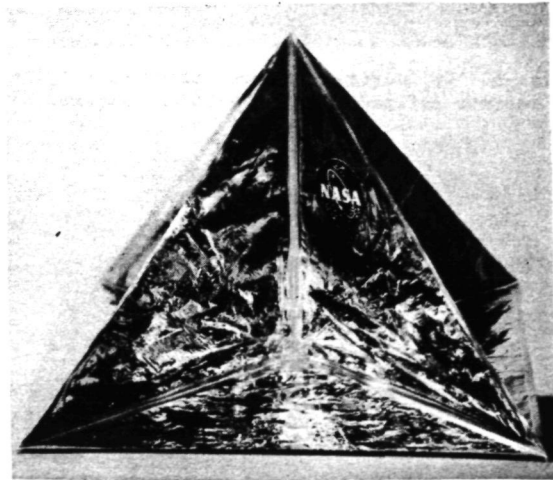


Fig. 4. Pop-up-reflector (four-corner reflector array) 45.4 cm edge.



Fig. 5. Cylindrical balloon reflector (eight-corner reflector array) 91.4 cm diameter.

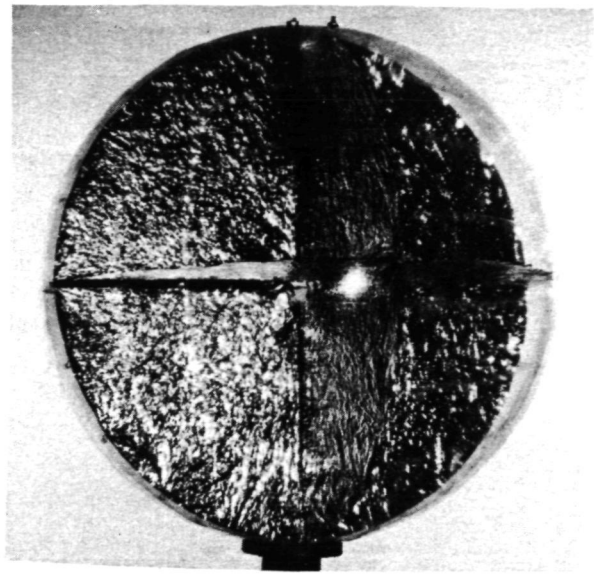


Fig. 7. Spherical balloon reflector (eight-corner reflector array), 91.4 cm diameter.

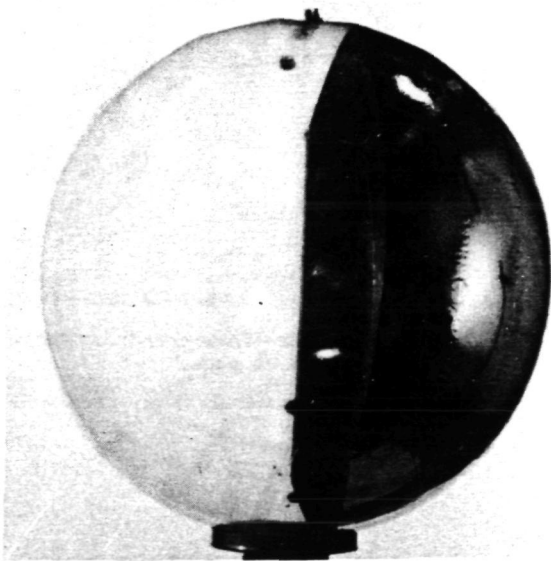


Fig. 6. Hemispherical balloon reflector, 63.5 cm diameter.

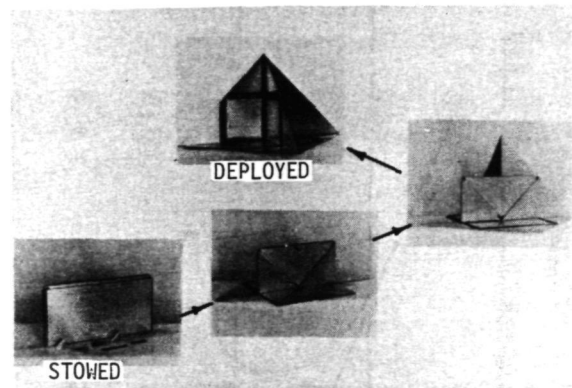


Fig. 8. Poly-fold reflector (four-corner reflector array), 61 cm edge.

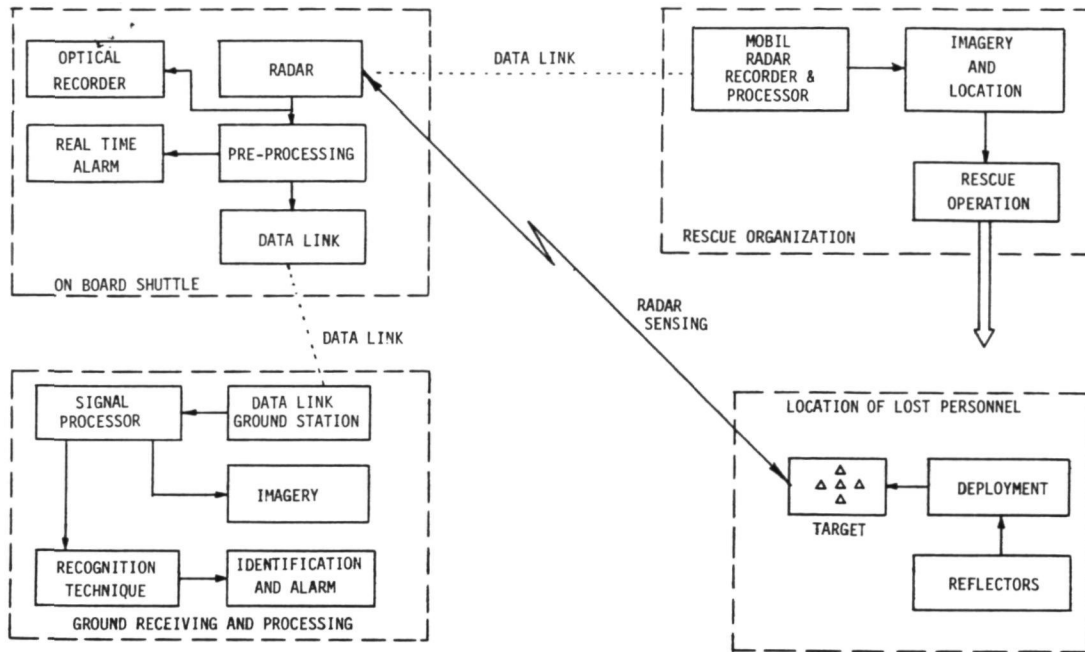


Fig. 9. Shuttle experiment search and rescue radar system - conceptual block diagram.

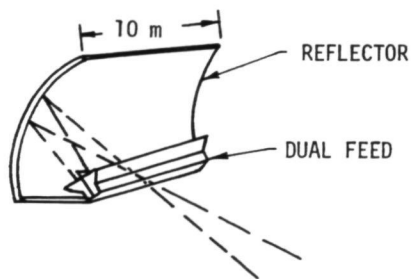


Fig. 10. Dual feed reflector antenna conceptual configuration.

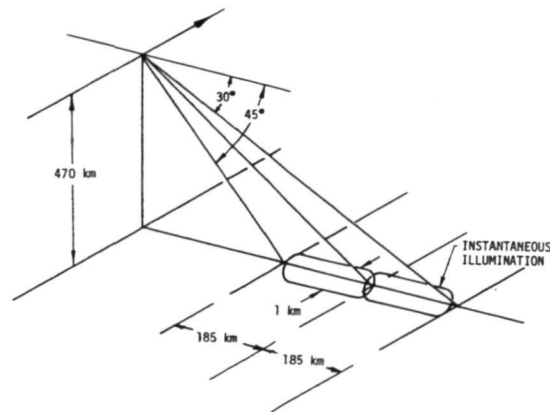


Fig. 11. Wide swath radar coverage geometry - dual beam antenna concept.

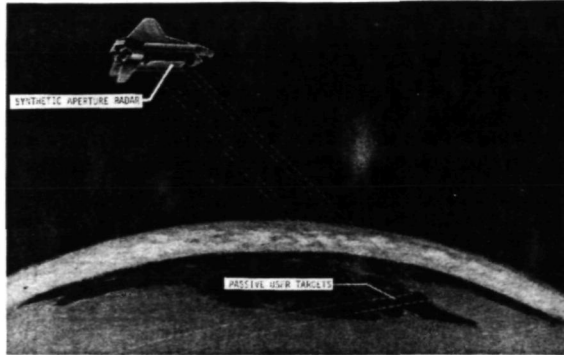


Fig. 12. Search and rescue shuttle experiment - artist concept.

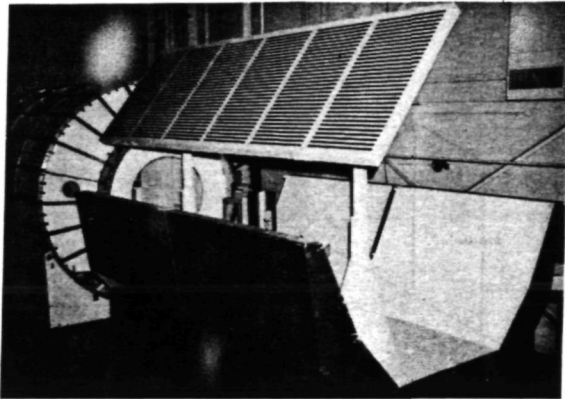


Fig. 13. Search and rescue full-scale mockup of Shuttle/Spacelab experiment.

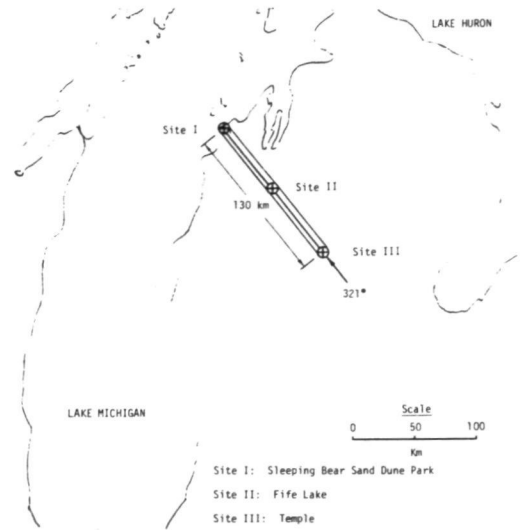


Fig. 14. Michigan search and rescue test area.

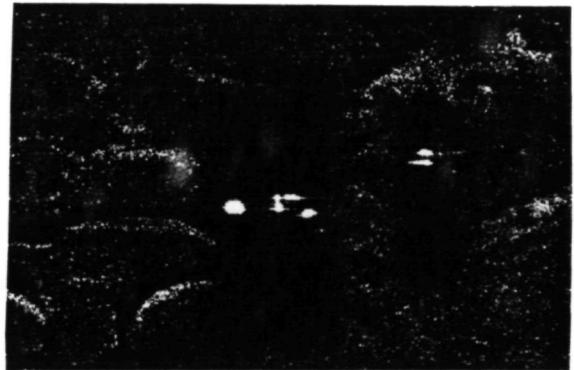


Fig. 15. Enlargement of radar image of Michigan Test Site III - horizontal polarization.

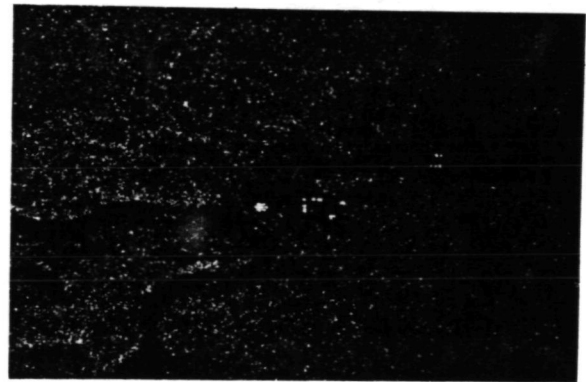


Fig. 16. Enlargement of radar image of Michigan Test Site III - vertical polarization.

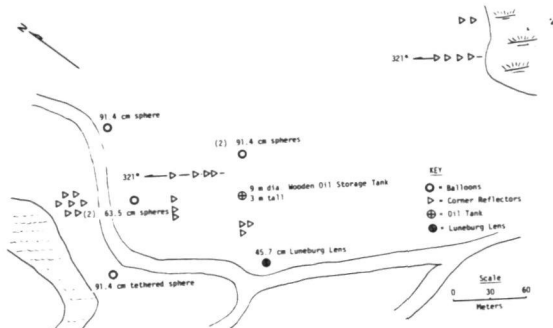


Fig. 17. Michigan Test Site III - reflector layout.

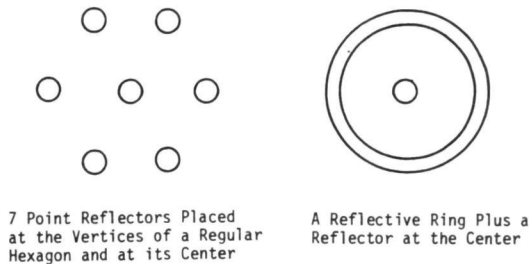


Fig. 18. Circular reflector array geometry.

TABLE I. - SUMMARY OF BACKSCATTER MEASUREMENTS ON REFLECTORS FOR SEARCH AND RESCUE (9.45 GHz HORIZONTAL POLARIZATION)

REFLECTOR TYPE	AVERAGED MEASURED σ dB*	REMARKS
4 Corner Pop-up #108	+11.5	Figure 4 Max Value
#103	+18.0	Max Value
#102	+20.4	Max Value
8 Corner - Cylinder Balloon #101	+24.5	Figure 5 Max Value
#100	+24.0	Max Value
	+11.5	Mean Value
Aluminized Mylar Sheet 30.5 cm x 30.5 cm	+20.5	Smooth Sheet
	+18.4	Rough Sheet
Hemisphere Balloons	+15.4	Figure 6 61 cm Dia.
8 Corner - Sphere Balloon #107	+21.4	Figure 7 Max Value
#106	+24.7	Max Value
	+11.0	Mean Value
Luneburg Lens 30.5 cm	+17.0	Max Value
45.7 cm	+22.0	Max Value
61 cm	+24.5	Max Value
Corner Reflector 45.4 cm	+21.3	A1. Structure Rigid

* Odb = 1 m² Target