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Image Interpretation in a Space Environment

What should a human interpreter be expected to identify from an orbiting vehicle?

(*Abstract on page 1012*)

Introduction

The anticipated near-future capability of extended duration manned orbital flights has generated much interest in the possible applications of manned space surveillance stations. Militarily such systems might be used to provide information related to surprise missile attacks, arms build-up, weapons deployment, and battle damage assessment. Numerous scientific applications have been considered, including the topographic mapping of the earth's surface, geological surveying, urban-area analysis, land-use planning, air-traffic control, iceberg monitoring, snow detection, studies of ocean currents and wave propagation, crop and forest inventories, astronomical studies, and, of course, weather observation.

The advantages of using man in space and the exact role he may be expected to play in such a system are, as yet, largely undetermined. Some people consider the manning of space surveillance satellites as an expensive luxury, because they feel that man's functions could be performed more economically with specially designed automatic equipment. Strong arguments can be raised, however, as to why man should be in such systems. It is not within the scope of this paper to attempt to resolve this dispute, but rather to examine some of the problems and variables that may relate to successful performance of image interpretation functions in a space environment. The anticipated task and training requirements for such a mission will also be discussed.

Man's Visual Capability in Space

The successful performance of image interpretation functions is contingent upon there being no serious degradation of visual performance capabilities resulting from the unusual conditions of a space environment. The data obtained thus far seem to indicate that there is little, if any, visual decrement associated with short-term space flight (Zink, 1963). Most of the astronauts and cosmonauts in fact reported seeing a finer level of detail than was predicted prior to the flights. The reported observations of astronauts who flew daylight missions over the Southwestern United States included cities, cultivated fields, roads, and railroads. Astronaut Gordon Cooper (1963), who enjoyed unusually favorable weather conditions, also reported seeing individual buildings and a vehicle in the pla-


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teau regions and mountains of India and Tibet. These objects were thought to be far beyond the resolution of the human eye. Close analysis of the reports, however, and their comparison with appropriate data for extended targets (*e.g.*, Hecht and Mintz, 1939; Taylor, 1964) indicate that the sightings were entirely possible for someone with Cooper's superior visual acuity (20/12).

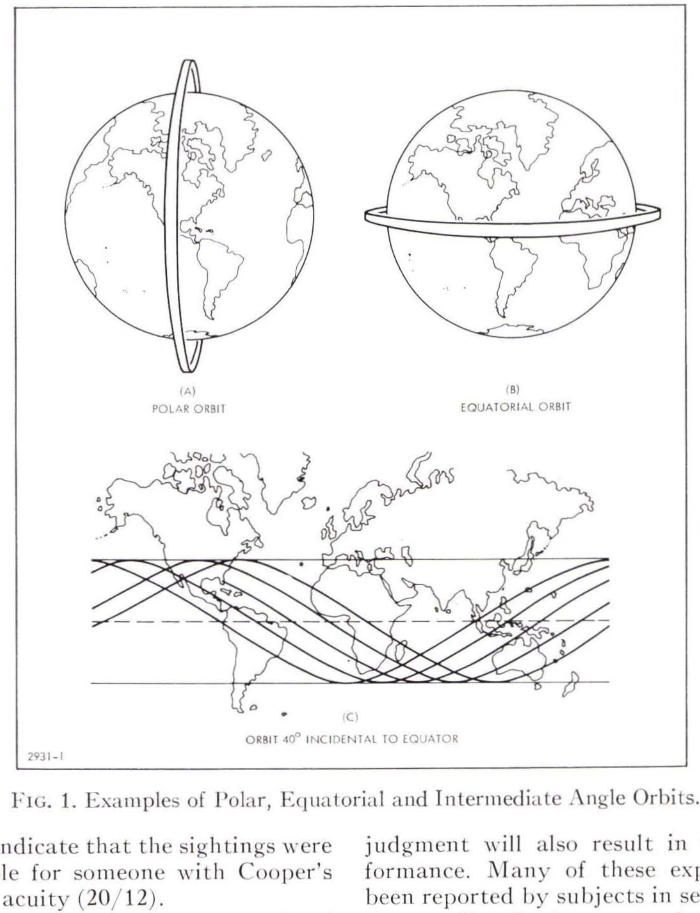

FIG. 1. Examples of Polar, Equatorial and Intermediate Angle Orbits.

Although most of the data about visual performance during short-term missions is of an anecdotal nature, there is little reason to anticipate serious degradation of visual capabilities on similar flights in the future. Little is known, however, concerning the possible effects on vision of prolonged exposure to weightlessness, isolation, confinement, reduced sensory inputs, and anxiety. Some of these variables have been studied singly and not always with encouraging results. Even if all such studies yielded no indications of resultant visual or cognitive impairment, it would still be difficult to predict what the interacting effect of these variables might be on visual and cognitive performance during long-term flights.

Any inability on the part of the interpreter to see clearly, to think coherently, or to direct thought processes on the displayed imagery for sustained periods of time, will degrade his interpretation performance. Tendencies to drift into highly personal and emotionally charged fantasy and loss of confidence in judgment will also result in degraded performance. Many of these experiences have been reported by subjects in sensory deprivation studies. So far, none of the astronauts, busy with flight plans and experiments during flight, has experienced anything approximating a sensory-deprivation condition. It is conceivable, however, that on a mission of longer duration, isolation, confinement, and reduced sensory inputs could have serious behavioral effects.

The effects of weightlessness on visual performance during the Mercury flights were of little significance. It is hoped that this will continue during longer duration missions. One possible source of annoyance to the spaceborne interpreter in a zero-g environment may be the tendency of the *muscae volitantes*[1]

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[1] Specks in the field of vision due to cells and fragments in the vitreous humor.

not to sink down spontaneously to the bottom of the eye globe (Schmidt, 1964).

The general relaxation of muscle tension resulting from prolonged exposure to weightlessness could also effectively lower an interpreter's altertness level and therefore his ability to perform search and surveillance tasks. Although the provision of artificial gravity may minimize these and other effects of weightlessness, the use of a rotating space platform greatly increases design complexity.

IMAGERY ACQUISITION AND PROCESSING CONSIDERATIONS

Assuming that visual and cognitive functions will not be impaired during long duration orbital flights, let us examine some of the factors influencing the anticipated quantity and quality of sensor imagery to be processed by the space-borne interpreter. The quantity of imagery is determined by the data-acquisition capabilities of the sensors, the total area available for viewing at a given instant, and the frequency with which desired areas may be viewed. The type of orbit selected for a manned space station fixes both the upper limit on the amount of the earth's surface available for viewing as well as the frequency with which a given area may be viewed.

As illustrated in Figure 1, a spacecraft may orbit in an equatorial plane, a plane passing through the poles, or in planes at intermediate angles. The equatorial plane restricts the satellite view area to an equatorial band of limited width. The polar orbit will enable a reconnaissance satellite to survey all areas of the earth's surface except in those cases in which the orbital period is an integral multiple or sub multiple of 24 hours (Rosenberg, 1958). The intermediate angle orbit, such as we have grown accustomed to in the Mercury flights, traces a wave-like pattern within a band equally spaced on either side of the equator.

In Figure 1, orbital path *C* is shown crossing the equator at an inclination of 40 degrees. An inclination of 80 degrees will cover all except the northernmost parts of the USSR, while an inclination of 50 degrees will cover all of this country except Alaska.

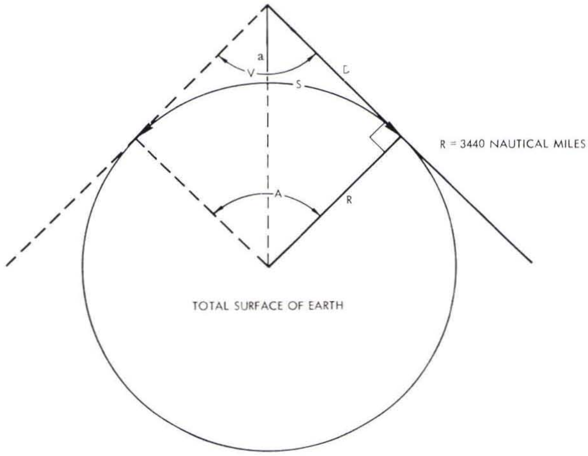
The amount of coverage, and thus the opportunity for obtaining imagery of desired areas, also increases as a function of altitude. As can be seen in Figure 2, at an orbital altitude of 300 miles, which is considered the minimum altitude level for long-duration flights, approximately 19 per cent or over 28 million square nautical miles may be available for viewing at a given instant. In a space surveillance system containing multiple sensors, the quantity of imagery which theoretically could be obtained with such vast coverage is staggering.

Thus far, we have only considered satellites with relatively fixed orbits. Maneuverable satellites, such as the winged reconnaissance satellite reputedly under development in the Soviet Union (Fusca, 1964), point out the variety of surveillance systems and orbital concepts that can be utilized. The Russian satellite has the projected capability of rapidly changing its orbital plane as well as its flight trajectory as it passes through the atmosphere at orbit perigee. Such a satellite could be highly effective in rapid and extremely evasive maneuvers at both high and low vantage points, and would provide greater flexibility in terms of changing the orbit to include coverage of new target areas of interest. The spaceborne interpreter may be involved in determining the orbital plane changes required to obtain imagery of specific targets beyond his present coverage.

The type, quantity, and quality of imagery available for interpretation in a manned space surveillance station will also depend upon the data-acquisition capabilities and reliability of the on-board sensors and the external conditions that may degrade the quality of obtained imagery. A wide variety of sensors might be included as part of a space surveillance system. Sensor selection would be based on the type of mission to be performed and the weight, space, power, and logistical-support constraints imposed by the system. In this paper, we will only consider factors which may affect the quality and quantity of data obtained from photographic, infrared, and coherent high-resolution radar systems in a space surveillance vehicle.

ABSTRACT: *Potential problems of image interpretation in manned space surveillance systems include the unique physiological, psychological, display and information-processing variables affecting interpretation performance under the unusual conditions of space. The interpretation task and training requirements are anticipated including suggestions for needed research.*

Of the three types of sensors, high performance reconnaissance cameras provide the best resolution and geometrically accurate production. It has been reported that a ground resolution of 16 to 20 inches has been obtained at altitudes of 100 to 120 miles (Fusca, 1964). Because of the high altitudes involved in space photography, however, it will be extremely difficult to obtain sufficient parallax for a useful stereo effect. Thus, one of the primary photographic interpretation tools may not be available to the spaceborne interpreter. Precise identification of man-made objects and structures will probably continue to be most easily made from photography. A major problem for the spaceborne interpreter, however, may be that photography of desired areas will be frequently unavailable when needed. Space photographic systems yield quantities of useful data only in good weather and during daylight conditions, although new techniques may provide night capability. The mean cloud coverage over the earth has been estimated as 54 per cent for land and 58 per cent for water (Brown, 1961). Although the amount of cloud cover may vary considerably, depending upon the geographical area and time of year, it is obvious that photography of areas outside of arid and semi-arid regions will not be available much of the time.



ALTITUDE (a, NM)	CENTRAL ANGLE (A, DEG)	VIEWING ANGLE (V, DEG)	MAX SLANT RANGE (D, NM)	VIEWING ARC (S, NM)	ORBITAL PERIOD (HRS)	PORTION OF EARTH VISIBLE (PERCENT)	APPROXIMATE AREA OF COVERAGE (NM)2
100	27° 06'	152° 54'	830	1600	1.22	11	16.25×10^6
200	37° 46'	142° 14'	1175	2260	1.27	15.5	22.9×10^6
300	45° 34'	134° 26'	1440	2740	1.3	19	28.1×10^6
400	51° 40'	128° 20'	1660	3100	1.34	21.5	31.8×10^6
500	56° 40'	123° 20'	1850	3370	1.375	23	34.0×10^6
1000	74° 32'	105° 28'	2620	4460	1.55	29.5	43.6×10^6

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FIG. 2. Viewing angles and coverageof earth's surface.

Degradation of the photography obtained, in the form of reduced contrast of ground objects, may also result from scattering and absorption effects in the atmosphere. Water vapor, smoke, dust, and other aerosols can obscure the ground and thus result in degraded photography of desired target areas. Unfortunately, this effect is often greatest in those areas that are of the greatest military interest, such as large cities and industrial areas. Gordon Cooper could not see cities such as San Diego or Calcutta when he flew over them. The only areas that were consistently clear throughout all the Mercury orbital flights were the western African desert and the Southwestern United States.

All of the problems posed by atmospheric attenuation effects are only slightly greater than those encountered in high altitude aerial photography and can be partly solved by filtering out some of the shorter wave light (Morrison and Bird, 1964). Brief periods of high visibility will also occur when the atmosphere is washed clean and excellent photography can be obtained.

Infrared and coherent high-resolution radar sensors presently lack the resolution capabilities of high performance reconnaissance cameras, but technological advances are swiftly narrowing this resolution gap. In general, fewer man-made objects and structures can be identified on radar and infrared imagery than on a good photograph of the same terrain. However, many objects can be detected on a radar and infrared display that are not visible on a photograph (*e.g.*, metallic objects no larger than a few feet in any dimension can be detected at great distances by high-resolution radars). Advances made in the development of radar and infrared imagery analysis techniques and training methods are constantly expanding the amount of information that can be extracted by the interpreter.

Infrared sensors, unlike space cameras, are largely unaffected by dust and haze and have a true day and night operational capability. Clouds and high surface winds, however, can greatly reduce image quality (Leonardo, 1964).

Coherent high-resolution radar sensors are capable of providing the largest quantity of usable imagery to the interpreter, because they are capable of day and night operation and can penetrate fog, haze, and clouds with minimum signal loss. Heavy rains can attenuate the signal, but the extent depends upon the system wave length. Of the three types of sensors, coherent high-resolution radar systems come closest to approximating a true all-weather capability.

DISPLAY CONSIDERATIONS

The selection of displays for spaceborne interpretation will be based on the type of interpretation functions to be performed, the number and type of on-board sensors, and the power, space, maintenance, and logistical-support requirements of the display systems.

To evaluate imagery displays for the specific type of interpretation task to be performed, the relationship of scale factor, display size, and resolution requirements must be carefully considered. Scale factor refers to the ratio of the length of the displayed image to the equivalent length of the ground object. A larger scale factor thus indicates that a larger linear dimension is being used to display the equivalent linear ground dimension than is the case when a smaller scale factor is utilized. For detection purposes, it is generally held that one minute of arc must be subtended at the eye under optimum illumination and contrast conditions (Crumley *et al.*, 1961). For accurate recognition, however, 12 minutes of arc is required for optimum viewing conditions and 20 minutes of arc for degraded conditions such as those encountered in operational situations (Steedman and Baker, 1960).

Figure 3 shows the relationship of the scale factor to ground element length for these three values. It can be seen, for example, that for accurate recognition of a ground object 100 feet in length, a minimum scale factor of 1:10,000 must be utilized under operational conditions. The scale factor finally selected fixes the total linear ground coverage shown on a display of a given size, and sets the limit on the size of ground objects that may be detected and recognized. Although the ground coverage may be increased by expanding the size of the display, this advantage may be offset by the resultant increase in search time requirements.

Another consideration in the selection of scale factor is the resolution of the display imagery. Results of a study by Williams, *et al.* (1960), suggest that utilization of an enlarged scale with poor resolution imagery may have a detrimental effect on interpretation performance because discrimination of objects, under these resolution conditions, is limited to gross or contextual clues. With increased resolution, identifications can be made based on small details; therefore, a larger scale factor may prove beneficial.

If the spaceborne interpreter is operating in a real time, or near real-time environment, the scale factor, display size, and vehicle speed will determine the time that a given target may be viewed. In a continuous presentation display, the rate of image movement across the display is directly proportional to the actual speed of the spacecraft. Figure 4 shows the target duration times for different scale factors on both 9-inch and 18-inch displays. These values are based on an assumed orbital velocity of 18,000 nautical miles per hour.

Studies have indicated that dynamic visual acuity is impaired with increasing angular velocity of a moving target starting to deteriorate noticeably with a speed of 20 degrees per second (Ludvigh and Miller, 1958; Goodson and Miller, 1959). The eye at these image movement rates is unable to match the exact rate of movement of the object. The resulting image motion on the retina reduces the con-

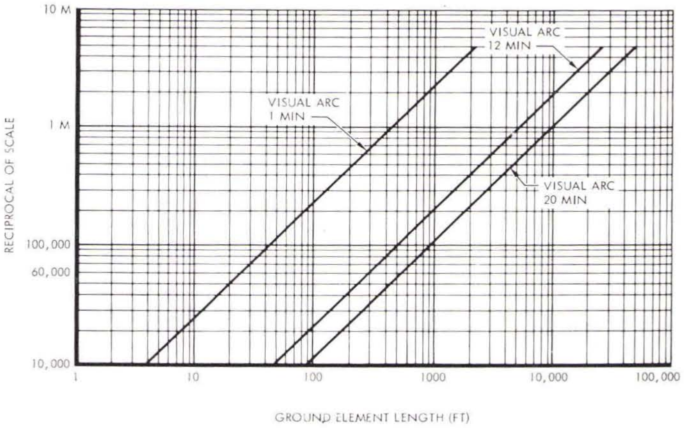

FIG. 3. Ground element size versus scale. (Viewing distance of 18 inches.)

trast and thus the visual acuity of the observer. At a viewing distance of 18 inches, such as we have assumed in Figure 4, an angular velocity of 20 degrees per second equals 6.45 in. sec. This then is the maximum image movement rate that may be used without impairment of visual acuity. As seen in Figure 4, to stay within these image movement rate limits, a scale factor not greater than 1:60,000 must be used. This, however, limits the size of the objects that can be detected and recognized. For example, at a scale factor of 1:60,000, only ground objects with a linear dimension greater than 550 feet may be recognizable under operational viewing conditions (see Figure 3). This may suffice for certain interpretive purposes, but may be inadequate for more detailed analyses. To circumvent this problem, some or all of the following display presentation options may be required by the spaceborne interpreter:

- *Intermittent Presentation Mode.* In this mode, it would be possible to store the information for a given period of time and present all of it simultaneously to the observer while the incoming returns for the next period are being recorded. This would provide the interpreter with a series of static displays rather than a continuous one.
- *Variable Speed Presentation Mode.* Utilizing this method, when the spaceborne interpreter wishes to make a detailed search of a particular area of interest, he would slow down or stop the imagery within certain time constraints, and then be able to adjust the rate to catch up.
- *Fractional Information Presentation Mode.* In this mode, selected portions of information could be omitted. The desired information could be stored for later presentation at a rate amenable to the interpreter's ability.

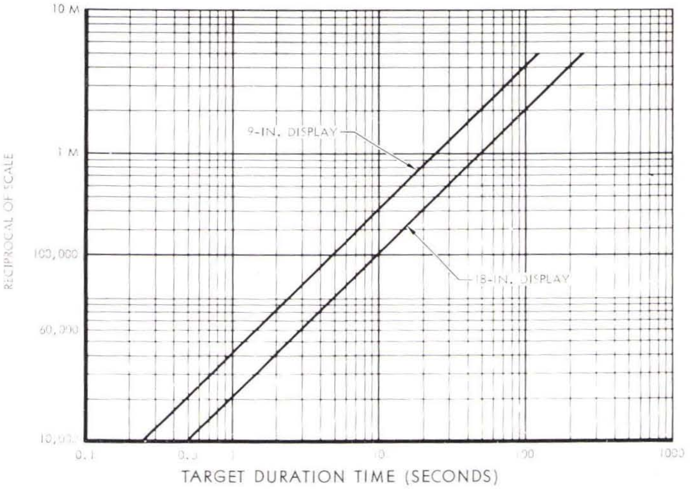

FIG. 4. Target duration time versus scale.

If multiple sensor imagery is to be viewed simultaneously in manned space surveillance stations, then a problem exists as to the best method of displaying the different presentations. At least four methods are available for simultaneous presentation of imagery from two or more sensors. The simplest method is the side-by-side technique. The primary disadvantage of this method, however, is the increased display area the interpreter must search through. Alternation of imagery presentations on the same display is another technique that might be utilized, but the constant switching of sensor imagery may prove irritating to the interpreter. Imagery presented via separate channels to the eye has been considered, but little is known concerning the effectiveness of this approach. The superimposition of displays through color filters appears to be a promising technique. This method is limited to imagery that is well-matched geometrically and of identical ground areas. Use of this technique may be difficult because of an excess of detail on the screen. The problem is further complicated by the fact that any mismatch must be less than the resolution of the eye, otherwise the composite display will appear degraded.

Other types of imagery display features that may prove desirable are variable magnification and illumination controls and a capability to rotate displayed images for particular interpretation purposes. The angular mounting requirements for the displays may also be changed due to the unrestrained body assuming a new relaxed posture in a weightless environment.

TASK AND TRAINING REQUIREMENTS

The specific tasks to be performed by the spaceborne interpreter have not, as yet, been well defined. It is possible that the spaceborne interpreter may be assigned solely to an imagery screening, filtering, and assignment-of-priority function to reduce redundancy in data to be transmitted to ground stations for detailed evaluation. There are indications, however, that his functions may extend well beyond that of present ground and airborne interpreters. Not only may he have to be expert in the characteristics and imaging properties of the on-board sensors, but he may be required to perform technical interpretive functions for a wide variety of military and scientific applications. Because crew size will be a limiting factor for long-duration surveillance missions, the spaceborne interpreter may be required to have a strong technical background in several areas, such as military intelligence, geology, hydrology, and meteorology.

The possibility of the interpreter being required not only to operate but also to maintain the sensor equipment cannot be overlooked. All of these considerations pose serious problems for our present interpreter-selection and training programs. Many of the interpretive techniques and tools that have been developed for use with imagery and photography obtained from airborne systems will be applicable to the spaceborne interpretation task. Special problems of interpreting imagery acquired and displayed in a space environment (*e.g.*, the small scale of obtained imagery and curvature), however, may require not only extensive modification of existing techniques but the development of entirely new ones as well (Lowman, 1964).

CONCLUSION

In conclusion, it can be seen that much more data must be obtained before an evaluation of the efficacy of manned space surveillance systems can be made. Some of the specific research questions requiring investigation before such systems can be a reality include:

- The ability of man to demonstrate reliable performance for long periods of time in a space environment.
- The information input and output limitations of the spaceborne interpreter for both screening and detailed analysis of imagery.
- The types of display configurations and interpretation techniques that will enable the interpreter to process the greatest amount of imagery in the shortest periods of time.
- The types of personnel selection and training procedures that are required for the anticipated interpreter functions.

The data obtained from such studies will largely determine the appropriateness of utilizing manned space surveillance systems for both military and scientific applications.

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