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NIGHTTIME/DAYTIME OPTICAL SURVEY OF LIGHTNING AND CONVECTIVE PHENOMENA EXPERIMENT (NOSL)

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FOREWORD

The Nighttime/Daytime Optical Survey of Lightning (NOSL) experiment has been selected by NASA Headquarters for flight on Orbital Flight Test 2 (STS-2) of the Space Shuttle. The experiment will be conducted by the astronauts from the cabin of the Space Shuttle. The Principal Investigator is Dr. Bernard Vonnegut of the Atmospheric Sciences Research Center, State University of New York at Albany. The Co-Investigators are Dr. Marx Brook of New Mexico Institute of Mining and Technology, Socorro, New Mexico, and Mr. Otha H. Vaughan, Jr., of the Space Sciences Laboratory, NASA Marshall Space Flight Center, Alabama.

The NOSL experiment is sponsored through the Severe Storms and Local Weather Research Program (Dr. James C. Dodge, Manager), NASA Headquarters, under Contract NAS8-32893. The authors of this report also acknowledge the outstanding engineering and integration support provided by personnel of the Experimental Systems Division at Johnson Spacecraft Center in the development of the experimental hardware and its integration with the Shuttle.

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1. INTRODUCTION

Thunderstorm electrification is a difficult research problem because many different processes produce charge separation within the clouds. Clues relating to the origin of cloud electrification may conceivably come from experimental data collected during space flights. Of interest at the present time is the fact that lightning has been observed on Venus and Jupiter whose atmospheres are radically different from that of the Earth.

Scientists performing research in atmospheric electricity are studying a phenomenon that not only has scientific research interest but also practical applications. The knowledge of the mechanisms that produce the electrical activity in storms cells could provide information for potential forecast, warning, and control of severe storms.

Improved information on the worldwide distribution of lightning is one important parameter that can be determined from an orbiting platform such as the Space Shuttle now scheduled to fly in 1980.

Verbal and written accounts from the Skylab astronauts indicate that a vehicle orbiting several hundred kilometers above the Earth affords a new and exciting overall view of thunderstorms and lightning that can never be seen at lower altitudes. The purpose of the Nighttime/Daytime Optical Survey of Lightning (NOSL) experiment is to obtain, by means of a movie camera and a lightning detection sensor, data on ordinary and severe storms that can be later analyzed by researchers to provide new quantitative information on dynamic and electrical phenomena. In addition to the photographic film, the appearance of lightning discharges will be recorded by a photo-optical sensor. The electronic output will be recorded using a magnetic tape synchronized with the camera film. In this way the frequency of the lightning and its characteristics both by day and by night can be correlated with the cloud structure and, when it is visible, the characteristicts of the lightning channel. If the experiment is successful, it is believed that adaptation of these techniques may prove to be useful for identifying severe weather situations from meteorological satellites.

2. TARGET PROBABILITY

The area of the Earth's surface that will be visible during the orbital flights of the Space Shuttle is so large that it is probable that storms capable of producing lightning will be visible on almost every orbit. Because of the high orbital speed of the satellite, these storms will remain in view for only a rather brief time--only a matter of minutes for storms lying beneath the satellite, and somewhat longer for storms more distant from the satellite path. Thus targets of opportunity can be selected by the astronaut.

2.1. Nocturnal Storms

During the passage over the dark side of the Earth the astronaut observers on the Space Shuttle should readily be able to recognize storms by lightning flashes either inside or outside the cloud, which should be visible for ranges of at least many hundreds of kilometers. Turman [1] has obtained excellent optical/electronic signatures using a lightning detector flown on the Defense Meteorological Satellite program. Vorpahl et al. [2] have also obtained photographic data for lightning activity using a satellite system.

2.2. Daylight Storms

Since most severe thunderstorms occur over land where the maximum frequency and the maximum intensity of thunderstorms occur during the periods of maximum solar heating, thunderstorm observations on the bright side of the Earth will be of importance for study.

During daylight hours it will be somewhat more difficult for the observers to recognize these storms because the lightning will not be visible to the eye against the brilliant background of sunlit clouds. If prior to the flight the observer is made familiar with the appearance of the tops of vigorous cumulonimbus clouds and anvils as viewed from above, it is probable that he will be able to identify lightning-producing storm systems by their appearance.

Although it is anticipated that the observer will be capable of identifying electrically active severe storm systems on the basis of their appearance, he will be alerted to the possible existence of additional severe storm systems. Ground observers, supplied with information from meteorological networks and satellite observations, will help him to identify areas of particular interest.

3. IDENTIFICATION OF LIGHTNING IN DAYLIGHT

It is anticipated that the photocell sensor system and the camera to be used in this experiment will be of use not only to provide a record of the lightning activity associated with nocturnal storms that are photographed, but also will be of great value in identifying areas of strong electrical activity during the day. It is planned that prior to and during the exposure of film the observer will survey cloud systems with the camera and sensor while listening to the output on an earphone. In this way he will be able by listening to the signal from the sensor to determine the areas in which the strongest lightning is occurring. Once having encountered an area of vigorous lightning activity, he can then record the appearance of the clouds in this region and the electrical signature of the lightning.

Certain features of interest during thunderstorm activity that only rarely can be seen from the Earth will be visible from the vantage point of the orbiting Space Shuttle. An important objective of the experiment will be to look for such unusual phenomena and to document them both photographically and electronically.

4. FEATURES OF INTEREST

The following are features of thunderstorm activity that would be of particular interest:

4.1. Long Lightning Discharges

There are a few reports [3,4] in the scientific literature describing both visual and radar observations of lightning discharges of unusual length, sometimes as long as 150 km. Such discharges would not ordinarily be visible from the ground or from aircraft, but may be readily identifiable when viewed from above. Photographs of such discharges would be of considerable scientific value.

4.2. Unusual Lightning in Tornado-Producing Storms

Airline pilots flying in the central U.S. have stated [5] that they often can identify tornado-producing storms by the very unusual lightning phenomena they produce. Although no photographs of this activity have apparently been taken, the descriptions indicate unusually frequent lightning and sometimes lightning of various colors. Some of these descriptions suggest that the top of the clouds appears as a "sea of fire." Still and cine photography of this unusual lightning activity would be a valuable contribution to our understanding of tornado-producing storms. If tornado-producing storms can be observed from orbit during night, the photographs and photocell recordings may shed new light on the puzzling electrical activity that is often associated with severe tornadoes [6,7].

4.3. Electrical Discharges in the Clear Air Above Thunderstorms

Observations of thunderstorms, particularly of the more intense variety, sometimes include descriptions of electrical discharges unusual in that they are occurring not beneath, or within thunderclouds, but in the clear air above them. Such descriptions [8] include not only what are apparently normal lightning discharges, except for the fact that they extend upwards into the clear air of the stratosphere above the cloud, but also luminous pillars of light and glowing fireballs. At present there are no photographs of this phenomenon, and it would be of great value if pictures could be secured from the Space Shuttle for detailed studies.

4.4. Changes in the Reflection of Sunlight from Upper Part of Thundercloud as Result of Electrical Reorientation

There are a few observations made from the ground and from high-altitude airplanes flying above thunderclouds showing that the intensity of sunlight reflected from the upper part of the cloud fluctuates during the currents of lightning discharges. This effect, observed by Vonnegut [9,10], is probably produced by electrically caused reorientation of ice crystals and would occur when the direction or intensity of the electric field changes as the result of lightning. It is to be expected that this phenomenon may be visible from a satellite and that it may be possible to document it with a motion picture camera. Probably the largest fluctuations of this sort would be observed when the thunderstorm system lies in the plane determined by the observer, the Sun, and the center of the Earth. At this position specularly reflecting ice crystals might be expected to show the most dramatic effects under the influence of the thunderstorm's electrical forces.

4.5. Cloud Circulation

Despite the brief time that strongly convective cumulonimbus clouds will be in the field of view of the observer, it may be possible to recognize interesting cloud dynamics. Observers should be alert to the possibility of recognizing regions of convergence and divergence in thunderstorm cloud areas and perhaps regions of strong rotation. If these can be documentd by the camera, the data will be of considerable value to students of storm and cloud dynamics.

4.6. Maritime Thunderstorms

The limited available lightning detection measurements made from satellites [11] indicate that far less electrical activity takes place over the oceans than over land. Because these observations provide no structural details of the storm or of the lightning, results are difficult to interpret. It will add to our understanding of the differences between electrical activity over land and over water if we can secure pictures of typical marine thunderstorm activity both by day and by night. Subsequent analysis of the photocell output may provide new information on whether there are differences between the number of strokes and the spacing between strokes in storms over the ocean and those over land.

4.7. Warm Cloud Electrification

Students of thunderstorms are agreed that most of the cloud systems that produce lightning are large and vigorous cumulonimbus clouds that rise to altitudes well above the 0°C isotherm. This fact has led many investigators to conclude that the ice phase may be of great importance in the processes that lead to the formation of charge centers responsible for lightning. There is evidence, however, that on occasion smaller cumulus clouds can sometimes produce lightning even though they are everywhere above freezing temperatures. There are several apparently well-authenticated reports [12-14] of warm cloud lightning in tropical or semitropical environments, such as the waters off Grand Bahama Island, Key West, and Viet Nam. If the existence and the characteristics of warm cloud lightning can be documented through satellite observations, it will represent a valuable contribution to our knowledge of cloud electrification.

4.8. Electrical Activity in Hurricanes and Typhoons

At the present time there is only extremely limited, somewhat contradictory information [15] concerning the electrification of these large tropical storm systems. According to some reports, there is extraordinary and continuous lightning activity associated with the walls of the eye of the storm. On the other hand, there are reports of otherwise similar storm systems in which lightning activity is almost entirely absent. It would be of great interest to photograph and record any hurricanes or typhoons or large tropical storm systems to learn more about the internal electrical activity associated with their growth and development.

4.9. Lightning in Volcanic Eruptions

In the event that vigorous volcanic eruptions can be observed from the orbiting Space Shuttle, it will be of great interest to observe them both by day and by night to ascertain the nature of any electrical activity that is occurring. It has been reported [16,17] that the lightning activity attending some volcanic eruptions sometimes rivals or even exceeds the intensity of lightning accompanying large thunderstorms. It will be of considerable interest to compare these two rather different intense sources of atmospheric electricity.

4.10. Relationship between Cloud Types and Lightning

Lightning observations made thus far from the ground and aircraft suggest that most lightning-producing clouds exhibit strong vertical circulation characterized by convective cauliflower tops. It will be of interest to determine by Shuttle observations whether lightning, detected by the human eye or by the photoelectric system, can ever occur in cloud systems in which little or no penetrative convection is occurring as indicated by smooth cirriform anvils or a smooth stratiform layer.

4.11. Spectroscopic Observations of Lightning

Spectroscopic studies of lightning by Orville [18,19] have proven useful in providing information on details of lightning, such as the pressures and temperatures that are developed in the plasma. Thus far, practically all spectroscopic observations have been confined to cloud-to-ground discharges. On the basis of descriptions of lightning provided by the astronauts it appears that it should be possible to obtain spectra looking down from the Space Shuttle that will yield new information on the characteristics of the lightning occurring in the upper parts of the thundercloud where the atmospheric pressure can be as much as an order of magnitude lower than it is at the ground.

5. DESCRIPTION OF NOSL HARDWARE

The NOSL camera and sensor system (Fig. 1) that the astronauts will use during the second Shuttle orbital flight test (STS-2) to make observations of thunderstorms and lightning is a modified version of the super-8 cine camera system (Fig. 2) described by Vonnegut and Passarelli [20]. This system consisted of a super-8 sound motion picture camera equipped with a photocell sensor system arranged so that it had approximately the same field of view as the camera lens in telephoto position (approximately 6 degrees). The electrical impulses produced when the photocell was illuminated by lightning were introduced into the amplifier of the camera and recorded on the magnetic sound track of the film. The system was used to photograph and record optical signals from lightning under a variety of circumstances, including severe storm reconnaissance flights on the University of Chicago Lear jet, flights on commercial jet airlines, and from various locations on the ground. Figure 3 shows a cloud-to-ground lightning discharge as it appeared on two adjacent frames of motion picture film. Figure 4 shows the details of the photocell output as recorded on the film sound track and displayed on an X-Y plotter.

Figure 4 is a record of the optical sensor output from a cloud-to-ground lightning flash recorded on the sound track of the Bolex super-8 film camera. The optical record, when correlated with the camera photographs, can be used to infer that there was a maximum of four separate return strokes. The optical signal shows some initial cloud activity, approximately 110 ms before the first return stroke. Approximately 30 ms before the first stroke there is again optical activity culminating in a stepped leader. The first three large pulses are undoubtedly return strokes. The two motion picture frames shown in Figure 3 exhibit the same geometrical channel to ground, but the first frame shows numerous branches typical of a first return stroke. Because the time between frames is 50 ms, the first three large, light pulses, plus the fourth smaller pulse, which also appears to show a leader, were probably included on the two frames of the film. A number of later pulses are present in the sensor record which do not exhibit counterpart visible channels on the film. These pulses must therefore originate from processes within the cloud. They are probably representative of what is normally identified as K changes. The four arrows on Figure 4 indicate the four pulses that are the return strokes. The photographic records plus the optical sensor records, when used together in analyzing the data, provide considerably more knowledge in interpreting the phenomena under study than is provided by a single record.

In the NOSL system (Fig. 1) to be flown on the Space Shuttle a 16 mm Maurer data acquisition camera and sensor will be used instead of the prototype super-8 system to photograph thunderstorms and lightning events because of its higher framing rate of 24 frames per second. Since the framing rate of the 16 mm camera is one-third greater than the super-8 camera, it will give somewhat better time resolution of the lightning discharges and, also, its larger film format will provide significantly better photographic resolution of clouds and lightning. The total experiment weighs 15.75 kg (34.7 lb) and occupies a volume of 0.028 m^3 (1.01 ft^3). The 16 mm film is color film (QX-807 with 2A filter).

The 16 mm Maurer is not a sound camera, and therefore the electrical signal from the optical system instead of being recorded on the film will be recorded on separate tracks of a 2-channel cassette tape recorder. One channel will be used to record the signal from the sensor while the other channel will be used to record pulses generated by the camera when each frame is exposed so that later it will be possible to synchronize the film with the record of the lightning.

6. EXPERIMENTAL PROCEDURE

When the Space Shuttle is in orbit, the astronaut will open the equipment-carrying cases, or lockers, (Fig. 5) and unpack the camera, sensor and electronics package, tape recorder, and associated equipment. He will then assemble the experimental hardware, place the five film magazines, three cassette tapes, and diffraction grating in the inflight stowage bag, load the camera with a film magazine, load the tape recorder with batteries, and install a tape cassette in the recorder. He will then proceed to the flight deck where he will stow the tape recorder in its assigned location, mount the inflight stowage bag, and mount the camera and sensor package on the adapter located on the top of the mission specialists console panel (Figs. 6 and 7). To provide fiducial marks on both tape and film that can later be used for establishing synchronization, the equipment will be pointed at a modulated light source, such as a fluorescent bulb, and turned on for a burst of a second. This check will also insure that the equipment is in operating condition. Having assured that the camera is now ready for operation, the observer will proceed with the camera to the window providing a view of the target. At night the individual lightning events to be photographed will be clearly visible to the unaided eye, and the observer will frame the target in the viewfinder and adjust the zoom lens (or choose the proper lens) to accommodate the scene to be photographed. For nighttime operation the observer will check to be sure that the lens aperture is wide open to supply the maximum amount of illumination; and, unless instructed otherwise from ground control, he will also mount the diffraction grating that will be supplied. He will monitor the sensor output and will identify the observation, stating date and time. He will then begin photography until either the storm is no longer in the field of view or the film indicator shows that the film has been exhausted.

During daylight the observer will be sure the diffraction grating has been removed from its holder and will adjust the lens to give proper exposure of sunlit clouds. Because lightning may not be visible to the observer, it will be necessary for him to determine its location by means of the electro-optical system. To do this, he will insert the earphone into his ear and, after depressing the audio monitor button, scan the storm system to determine, by listening to the series of impulses produced by lightning, where the maximum electrical activity is occurring. As in the case of nocturnal storms, he will photograph the region wherein the maximum activity is occurring.

Following the exposure of film, the observer will note the time of the exposure, number of the magazine, remove the film magazine if less than one-fourth of the film remains, note on the film magazine the time of the exposure, and replace it in its slot in the inflight stowage bag. A new, numbered film magazine obtained from the bag will then be inserted and locked on the camera, ready for the next observation. At the end of the mission, any film cartridge remaining in the camera should be removed and placed with the rest of the exposed film for processing.

It is planned that the astronaut and the Principal Investigator and the Co-Investigators will be in contact prior to the start of the experiment to discuss with the crew members the location of possible storm cells and their location relative to the orbital look angles from the Shuttle. Also planned are discussions with the crew members after the first photography has been completed using the NOSL system. After completion of the experiment, discussions will be held again with the crew members to incorporate any suggested changes in the presently designed hardware for future observations.

7. DISCUSSION OF DATA ANALYSIS TECHNIQUE

The data taken in the NOSL experiment will comprise motion pictures of thunderstorms taken with a 16 mm color film data acquisition camera and sensor signals produced by lightning in the same area as the photographs and recorded on a dual-channel cassette recorder. The photographs will show the appearance of convective cloud systems by day and lightning activity in thunderclouds during the night. The recorded sensor data will give information on the frequency and characteristics of lightning occurring in the field of view of the camera both by day and by night. Details of the time and place of thunderstorm observations and noteworthy characteristics of these storms will be voice recorded by the astronauts on one of the channels of the cassette recorder. There will probably be additional data provided on the operation in the form of notes and interviews obtained during debriefing.

The first stage in the data analysis will be the processing and duplication of the 16 mm film and the duplication of the stereo tape from the two-channel cassette tape recorder. The next stage in the data reduction will be to produce a 16 mm sound film in which the data from the photocell on the tape recorder will be synchronized with the film by the use of the synchronizing pulses on the cassette recorder.

The film with synchronized sound track will then be viewed by the scientific investigators as it is projected on a conventional 16 mm magnetic sound film projector. When the film is viewed in this manner, the occurrence of lightning in thunderstorms will be indicated by the sharp acoustic impulses originating from the photo-optical signals recorded on the sound track. The initial viewing of the film should provide, by the occurrence of the sound pulses, an indication of the frequency of lightning stroke activity associated with various convective disturbances ranging from air mass storms to frontal situations to severe tornado-producing storms and hurricanes or typhoons. The sound track may provide some indication of the general region in which the lightning is occurring even though the lightning will, of course, not be visible on the 16 mm film during the day. It is anticipated that there will be wide differences in the electrical activity of the storms, as indicated by the frequency of lightning discharges. Each electrical storm observed will be categorized in terms of the frequency of lightning discharges. The data will be analyzed to determine how the lightning activity is related to such variables as the number of cells in the storm, the diameter of the cells, and the altitude of the cell top. Such data will hopefully give new information on scaling laws of thunderstorms and may provide insight into the nature of the electrification process that is occurring.

If a sufficient number of thunderstorms can be observed over the ocean as well as over land, comparisons can be made to determine whether the convective structure of these storms is similar to those over land and whether the relationship between lightning frequency and wave form to the convective development is the same as that observed over land. When a sufficient number of storms have been analyzed, it will be possible to calculate relationships between lightning frequencies over land and oceans.

Because little information is presently available on electrical activity in hurricanes, it will be of great interest to determine from the photocell data where the greatest electrical activity is taking place in hurricanes and typhoons and whether there is a relationship between the intensity of the storm and the accompanying electrical activity.

Because during the day lightning may not be seen by the eye directly or on photographic film, the only data concerning the electrical activity of the storm will be from the data taken with the photocell. While some indication of the activity of the storm can be obtained merely by listening to the sound track, a great deal more information can be obtained by detailed analysis of the signals on the magnetic tape, either with oscillographs or with digital recording devices or Fourier analysis. Lightning in various sizes and kinds of storms will be categorized in terms of the number of strokes per flash and the time interval between strokes. It may be possible by looking at the detailed structure of the flash to determine from the sensor data whether the discharge was intracloud or cloud-to-ground. If this proves possible, a study will be made to see if the convective structure of the cloud as viewed from above provides any clue concerning the ratio of these two types of lightning which is known to vary considerably from storm to storm.

The primary data of our nocturnal observations of lightning will be the lightning and cloud images on the motion picture film. In the initial qualitative study of the synchronized film and photocell data we will be particularly interested in instances of horizontal lightning discharges 100 km or more in length that have been described, but so far not photographed, by astronauts. We will be interested to learn whether such long horizontal discharges are a rather common feature of electrical activity or whether they are only associated with certain kinds of convective systems. If we are successful in obtaining examples of long horizontal discharges, we will make a frame-by-frame analysis of the film and calculate the velocity of the growth of the horizontal discharges. From simultaneous detailed analysis of the signal on the magnetic tape we hope to learn something of the details of the discharge. If it consists of cloud-to-ground strokes, we will determine the number of strokes and the time intervals between strokes. Such analysis should give some indication of the mechanism of propagation of these long discharges.

We hope that during the course of the astronauts' observations they will be successful in photographing at night a kind of vertical lightning discharge that has been described by a U-2 pilot [21] as originating from the top of an active thunderstorm and extending well into the stratosphere. From the photographic image and from the magnetic sound track we expect to be able to learn the duration of these discharges, their vertical extent, and whether they are of intermittent or continuing current variety.

Airline pilots have reported that the lightning occurring in tornado-producing storms is of an unusual, clearly recognizable character. If the Shuttle crew is fortunate enough to obtain data from a tornado-producing storm at night, we will carefully examine the images of the lightning occurring at that time to see if it differs from that in ordinary thunderstorms. This will include the study of the geometry of the discharges as well as a detailed analysis of the accompanying impulses on the magnetic sound track.

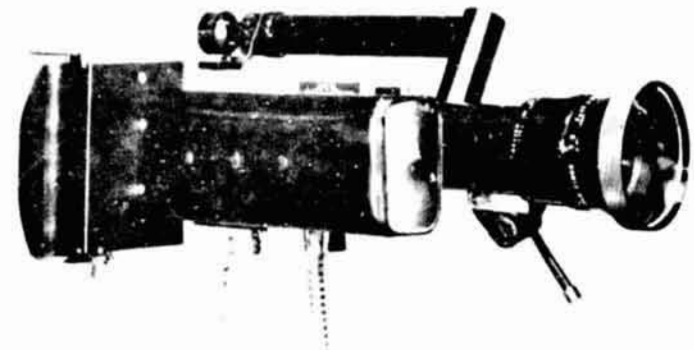
During most of the nocturnal lightning photography a diffraction grating will be placed on the camera lens so that in those conditions where the lightning illumination is sufficiently narrow we will be able to obtain slitless spectra of the lightning discharges. For each case in which there are well-defined spectra, the spectra will be provided to Professor Richard Orville of the Department of Atmospheric Science, State University of New York at Albany, who will examine them quantitatively to see how these spectra compare with those he has obtained on lightning channels at lower levels. When the spectra are compared with the detailed optical output of the flash as measured by the photocell, it may be possible to identify intracloud or cloud-to-ground strokes and conceivably other varieties of lightning not normally seen from the ground.

An advantage of any nocturnal lightning studies will be that the photographic images should clearly indicate whether the lightning channel being observed is in the clear air above or outside of the cloud or whether the lightning is from diffuse illumination originating from lightning at some depth within the cloud. In those cases where it can be determined that the lightning is not scattered or obscured by the cloud, it should be possible to obtain some measure of the electrical power of the stroke from the intensity of the photoelectric signal. In those cases where the lightning is deep within the cloud, the intensity of the photoelectric signal may be difficult to interpret.

8. CONCLUSIONS

Although the data acquired using development hardware from ground and from Lear jet and U-2 aircraft [20-22] have been excellent, there is little doubt that similar observations made by day and by night from the orbiting Space Shuttle will prove more valuable. While observations to date have necessarily involved long pathlengths through the atmosphere, satellite observations can be made with far less attenuation because of the short pathlengths through the upper thin, clear atmosphere. Furthermore, as we know from the data taken thus far, satellite observations provide a unique view of the complicated convective towers. It will be of interest to obtain motion pictures that will show how the frequency and intensity of lightning discharges are related to the intensity and convective structure of thunderstorms.

The Shuttle observations may shed new light on other little-understood aspects of atmospheric electricity, such as lightning activity in hurricanes, dust storms, and the unusual positive-polarity discharges reported by Takeuti and Nakano [23] off the Sea of Japan. The data that will be obtained should also prove invaluable in the design of future systems for continuously monitoring thunderstorm activity from space.



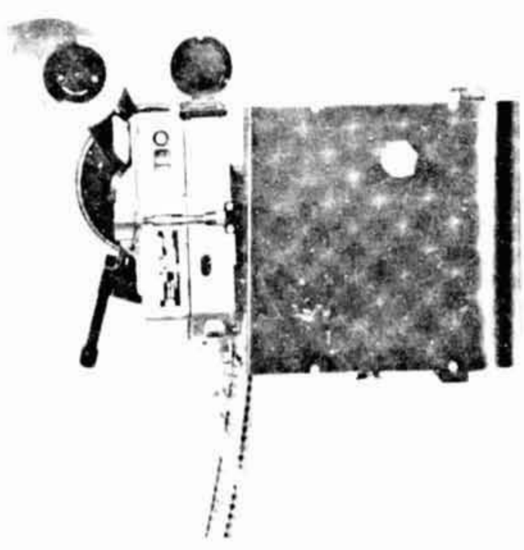


Figure 1. NOSL camera and sensor system.

Figure 2. Development hardware—super 8 sound camera and sensor.

Figure 3. Two adjacent frames from motion picture film of cloud-to-ground lightning discharge.
(Super 8 photography by O. H. Vaughan.)

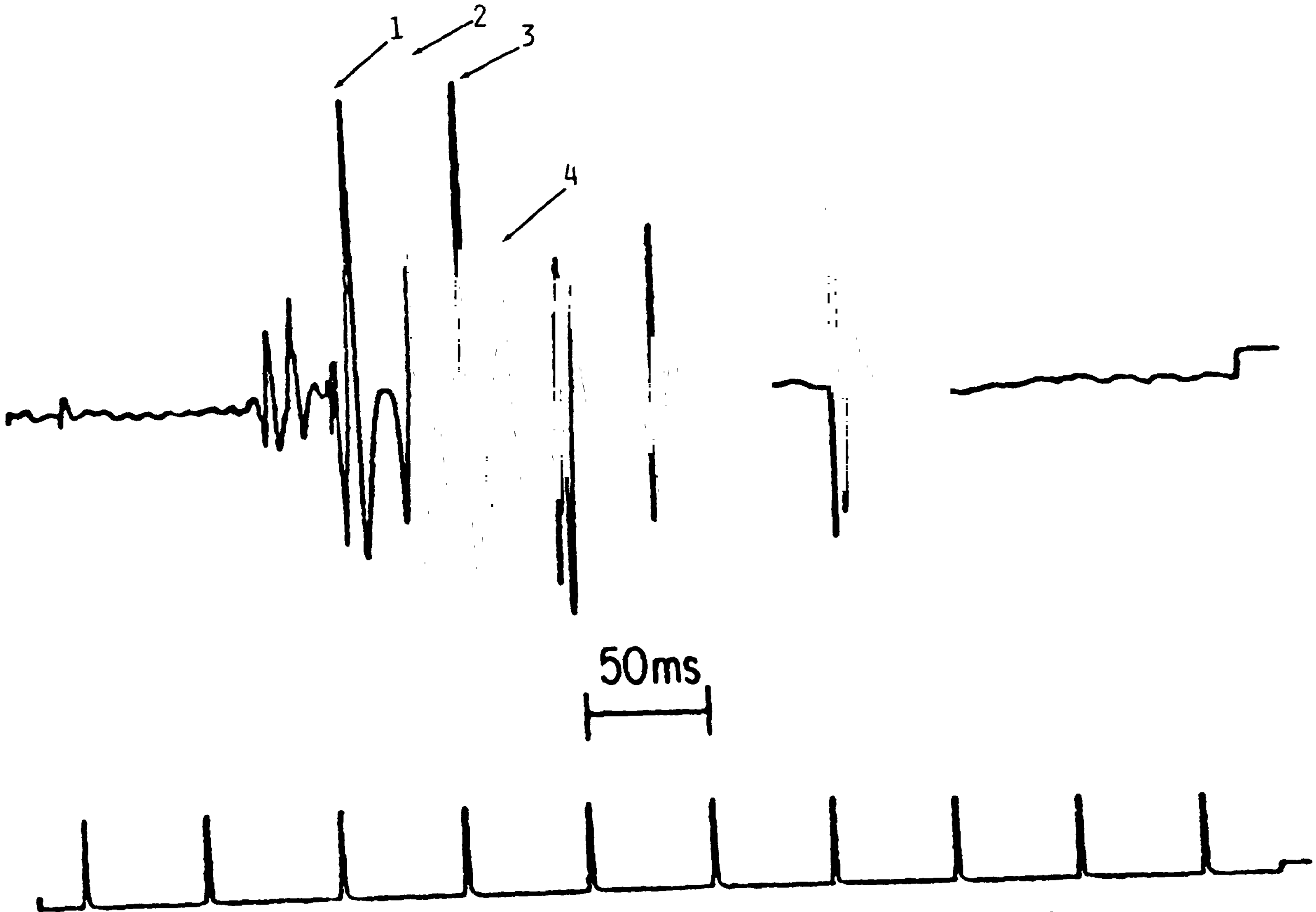


Figure 4. Data sample of cloud-to-ground lightning recorded with the sensor.

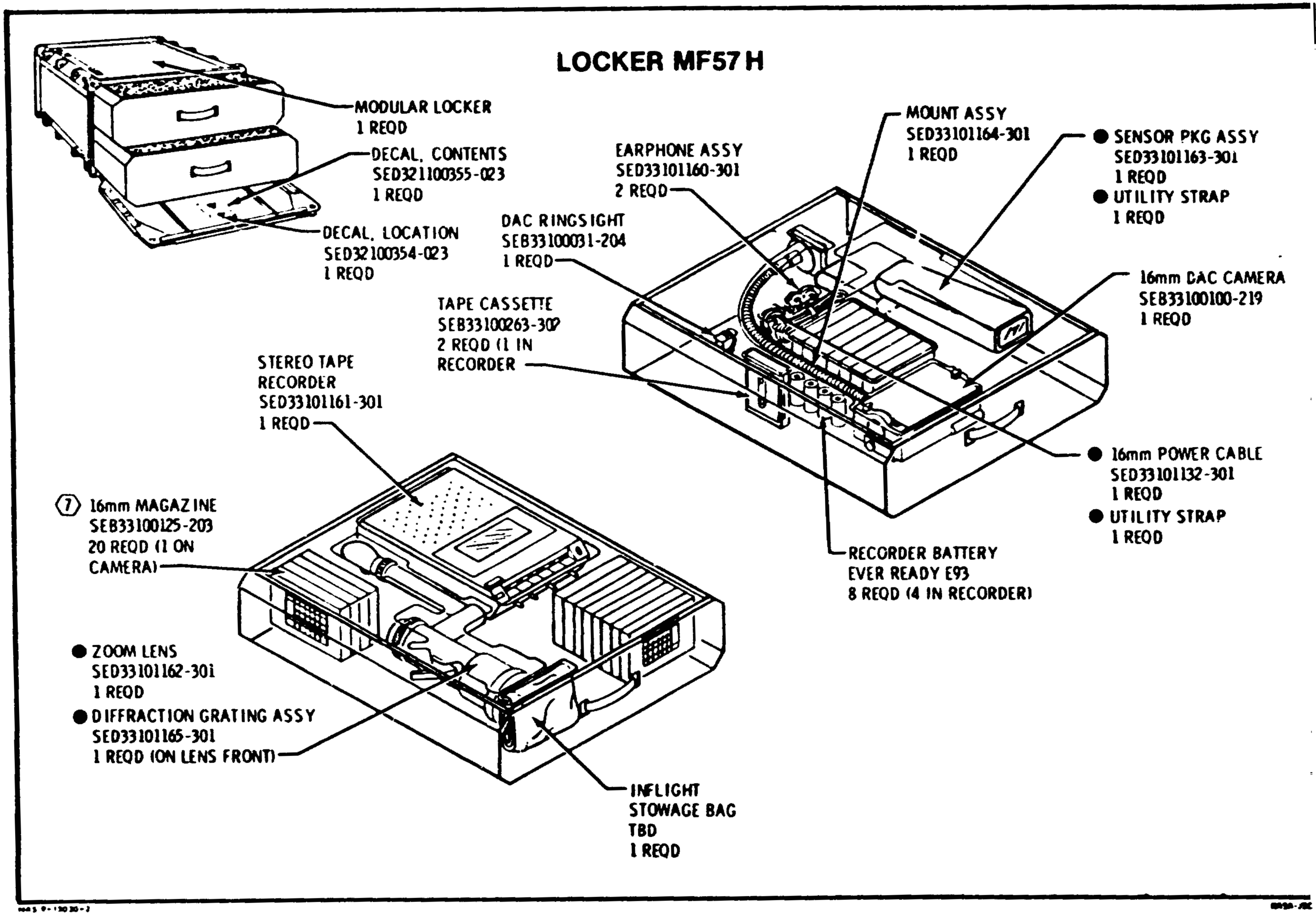


Figure 5. Equipment-carrying cases for stowage in the Shuttle.

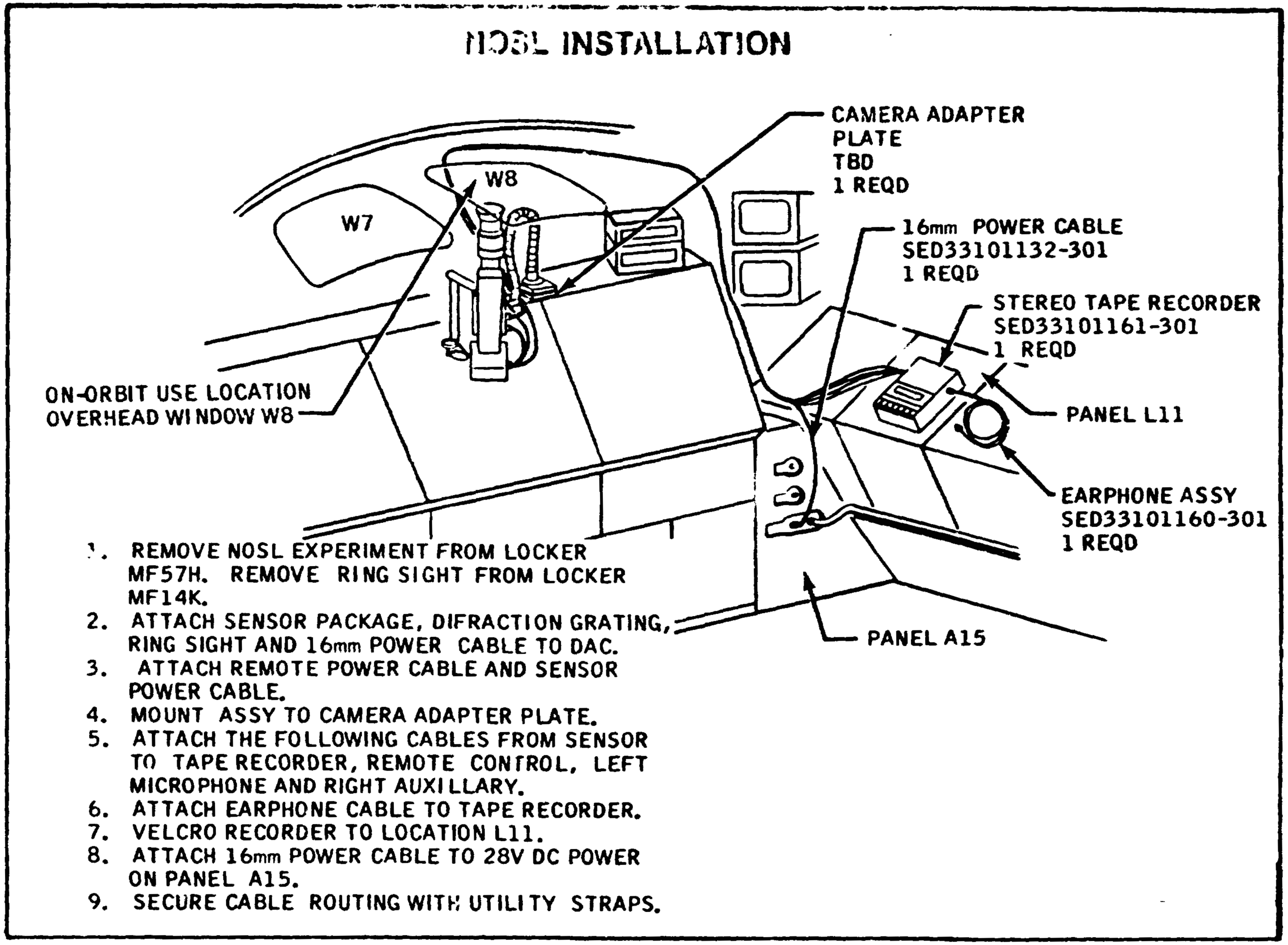


Figure 6. NOSL installation for stowage and operation on the flight deck of Shuttle.

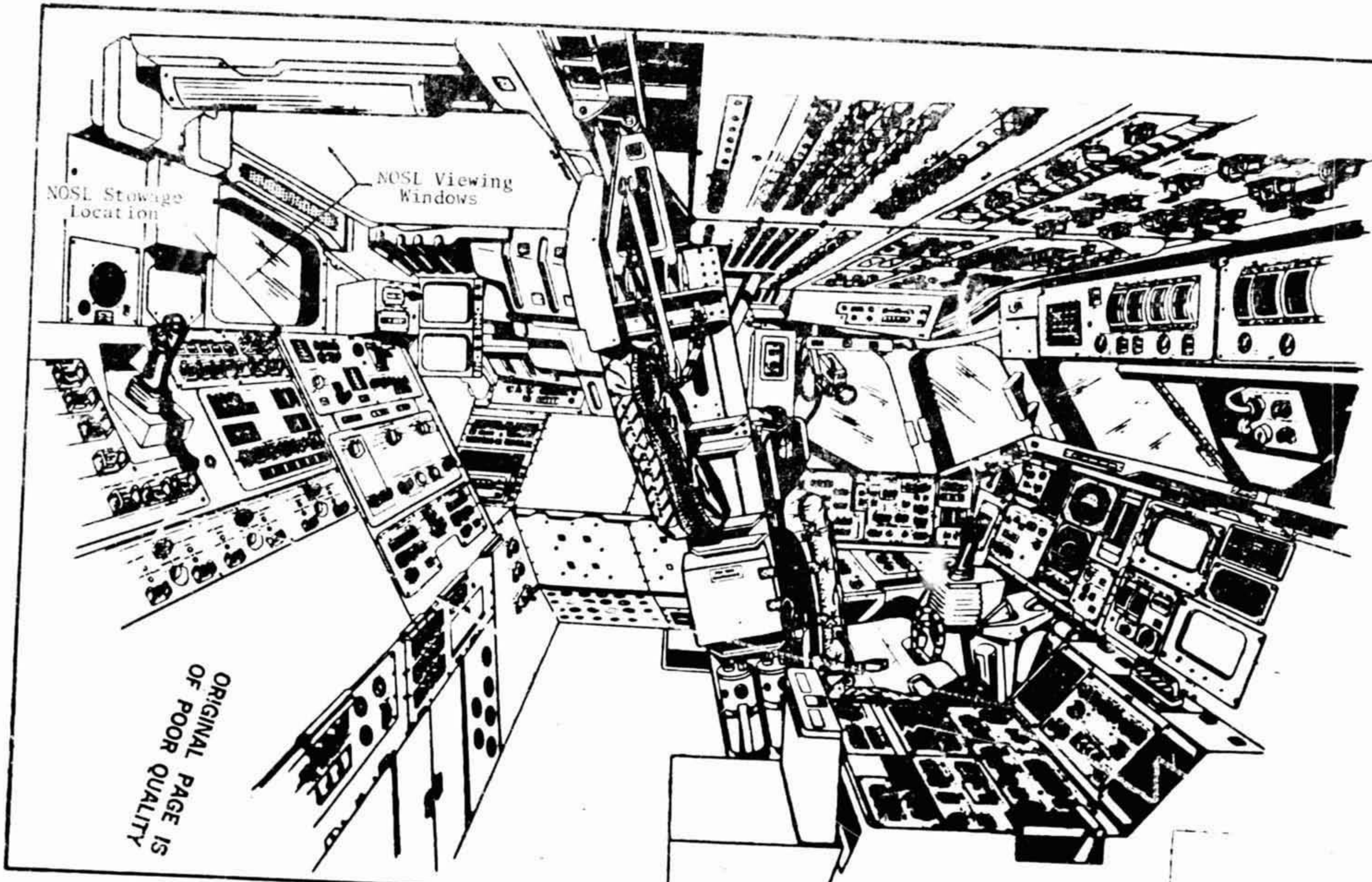


Figure 7. Flight deck, left side, on-orbit installation.

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APPROVAL

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By Bernard Vonnegut, Otha H. Vaughan, Jr., and Marx Brook

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Office This report, in its entirety, has been determined to be unclassified.

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