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ASTRONAUT HAZARD DURING FREE-FLIGHT POLAR EVA

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Extravehicular Activity (EVA) during Shuttle flights planned for the late 1980's includes several factors which together may constitute an astronaut hazard. Free-flight EVA is planned whereas prior United States earth orbit EVA has used umbilical tethers carrying communications, coolant, and oxygen. EVA associated with missions like Landsat Retrieval will be in orbits through the auroral oval where charging of spacecraft may occur.

The astronaut performing free flight EVA constitutes an independent spacecraft. The astronaut and the Shuttle make up a system of electrically isolated spacecraft with a wide disparity in size. Unique situations, such as the astronaut being in the wake of the Shuttle while traversing an auroral disturbance, could result in significant astronaut and Shuttle charging. Charging and subsequent arc discharge are important because they have been associated with operating upsets and even satellite failure at geosynchronous orbit. Spacecraft charging theory and experiments are being examined to evaluate charging for Shuttle size spacecraft in the polar ionosphere.

The extensive body of knowledge about auroral phenomena can assist in evaluating the importance of charging. Images recorded by the Defense Meteorological Satellite Program (DMSP) satellites in circular orbits show snapshots of the spatial extent of the optical aurora. Montages of all sky camera images from an aircraft flying a path to remain at constant local midnight show the cyclic behavior and the suddenness of onset of optical aurora. Geophysical conditions measured at the time can be used to evaluate the EVA conducted from Skylab in 1973-74. Skylab, with an orbit inclination of 50 degrees, did encounter the auroral oval when the orbit latitude extremes were at the right longitude and local time. Study of the geophysical conditions and orbits during the Skylab EVAs showed that astronauts on EVA were always at least 5 degrees of latitude equatorward of the auroral oval.

INTRODUCTION

In the process of evaluating space systems environmental interactions (Pike et al, ref. 1), it became apparent that physical interactions between the environment and the astronaut's extravehicular activity (EVA) equipment could be significant. Servicing of satellites after launch is an example of how astronaut free-flight EVA will be used. The EVA equipment now available for use, developed by the National Aeronautics and Space Administration (NASA) at the same time that the Shuttle was being developed, was designed for Shuttle flights at low inclination angles (NASA Johnson Space Center (JSC) Private Communication, 1982). At that time it was not anticipated that polar orbit EVA would involve additional problems.

The special area of concern to Air Force Geophysics Laboratory (AFGL) is with the physical interaction between the environment and the astronaut's EVA equipment, as opposed to the biological interaction between the environment and the astronaut himself. The effort has focused on the interaction of charging and arc discharges (Garrett and Pike, ref. 2) on the Extravehicular Mobility Unit (EMU), the Primary Life Support System (PLSS), and the Manned Maneuvering Unit (MMU). This interaction is important because of the consequences of EVA equipment failure in combination with the great uncertainty involved with charging and arc discharge in the Shuttle environment.

EXTRAVEHICULAR ACTIVITY

The polar orbit EVA to be conducted from Shuttle will encounter conditions differing from those encountered during the NASA successful EVA history during the Gemini, Apollo, and Skylab programs (Furniss, ref. 3). The NASA history of EVA has been one of outstanding success since the first EVA by White on the Gemini 4 flight in 1965. The Gemini program included 9 EVAs at low (several hundred kilometers) altitude and low latitude with the astronauts connected to the spacecraft by an umbilical tether carrying oxygen, coolant, and communications services. Approximately 20 EVAs were conducted during the Apollo program. Most occurred on the lunar surface with 3 in deep space while returning to earth. Although the lunar EVAs were untethered, they were in a deep space environment quite different from the Earth's ionospheric plasma. The 10 EVAs from Skylab were again in the ionospheric plasma with the astronauts connected to Skylab by an umbilical tether. Skylab's 50 degree orbit inclination intersected the auroral oval, the greatest overlap was in the southern hemisphere near Australia. However, the Skylab EVAs were conducted while the orbital latitudinal extremes were in other longitudinal sectors. The geophysical conditions encountered during the Skylab EVAs will be discussed later.

With this successful EVA history as a baseline, what is there about EVA from the Shuttle to cause concern? One significant factor is that at times the astronaut will be untethered and, if simultaneous failures occur, could "float away". Another factor is the development of Vandenberg Air Force Base as a Shuttle launch site. Vandenberg will have the capability of launching the Shuttle into high inclination orbits intersecting the auroral oval 4 times during every orbit. The environment at auroral oval latitudes is markedly different from that at low latitudes and is potentially hostile during geophysical disturbances. NASA is now considering a polar orbit Shuttle flight from Vandenberg to retrieve the Landsat-D satellite. The mission scenario is expected to include EVA and, possibly, free-flight EVA.

Polar Orbit Extravehicular Activity

The polar orbit EVA illustrated in figure 1 depicts the combination of circumstances which make polar free-flight EVA different from other EVAs to date. At the center is a graphical representation of analytical modeling of the Shuttle and an astronaut on EVA in the ambient ionospheric plasma (Cooke et al, ref. 4). The shape of the Shuttle is represented by different sized rectangular and triangular solids. The astronaut is represented as a 2 meter long, 1 meter diameter, dielectric cylinder. The Shuttle is large compared to the size of the astronaut, who will at times be in the wake, where electron and ion densities are decreased. The Shuttle is shown with the negative Z axis in the direction of motion and the payload-bay in the wake. The contours, more distinct in the original color illustration, show the decreased electron and ion density. The innermost contour represents 5% of ambient. Experimental plasma density measurements in the Shuttle payload bay on early flights have shown great differences between the payload bay in the ram direction, where the ionosphere has access to the payload bay, and the payload bay in the wake orientation (Shawhan et al, ref. 5). For some geometrical arrangements during flight through the auroral oval, such as depicted here, the Shuttle and the free-flying astronaut will both be exposed to the incident auroral electron flux. Conditions which support spacecraft charging will occur because of the auroral electron flux combined with the decreased electron density and, more importantly, the reduced thermal positive ion density in the Shuttle wake.

Existing Extravehicular Activity Equipment

Figure 2 identifies some of the surface materials used on the astronaut's EVA equipment (NASA JSC Private Communication, 1982). Many of these materials are similar, or even identical, to materials which were adversely affected on the SCATHA (Spacecraft Charging At High Altitudes) satellite and in laboratory studies of the charging of materials in space. Most of the space suit (EMU) is covered by Orthofabric which has a white surface consisting of expanded teflon. The astronaut's finger tips and shoe soles are silicon rubber. Much of the MMU is covered with the type of Chemglaze paint which has been found to exhibit charging on SCATHA and in other spacecraft charging studies. Some areas have silverized teflon and others have gloss white paint over glass/epoxy or kevlar/epoxy. The astronaut's helmet and the MMU locator light domes are Lexan. A similar material, Plexiglas, which has previously been used for transparent spacecraft components, is known to have been associated with charging. The metal foil decals used for a number of identifying labels, particularly on the MMU, may become involved with charging. Previously, isolated conductive patterns on printed circuit boards have suffered charging and deleterious arc discharges (Leung et al, ref. 6). The decals are an example of a seemingly innocuous item which becomes significant when conditions conducive to charging occur.

Figure 3 shows an astronaut equipped for free-flight EVA. The major equipment systems are the EMU and the PLSS used for all EVAs, along with the MMU used for untethered free-flight EVA. Some problems with EVA equipment can be direct life-threatening hazards to the astronauts. The failure of the PLSS circulating fan motor during the STS-5 flight is an example (Aviation Week, ref. 7). MMU failures are also potentially life threatening. A failure causing an MMU thruster to remain on would cause attitude control problems similar to those encountered by Gemini 8 where a spacecraft control system short circuit caused one thruster to fire continuously. The Gemini astronauts used 75% of their reaction control system fuel before recovering from the malfunction. This forced them to cancel the rest of their mission and return as soon as possible. Operational planning for EVA provides for the Shuttle going after the astronaut if there are multiple failures in the MMU redundant control systems. A MMU thruster malfunction leaving the astronaut spinning rapidly could complicate retrieval by the Shuttle, as well as be a direct danger to the astronaut.

Other EVA equipment problems which would limit EVA operations have just as much significance as life-threatening hazards, from the standpoint of failure to achieve the Shuttle mission objectives. Failure of an EMU astronaut communications link, while not a threat to the astronaut's life, would cut short a mission such as repair of the Solar Maximum Mission spacecraft. Failures in the helmet television or PLSS Caution and Warning systems also limit operations. EVAs would not be carried out without one of these systems unless, for example, it was necessary for the astronaut to close the payload doors for entry. The presently available EVA equipment uses advanced microelectronics for monitoring status, communications, etc., but not for direct control of life support subsystems. A change to direct microprocessor control of life support functions, proposed for future systems, could make failure even more significant.

Extravehicular Activity Near Solar Array Systems

Figure 4 illustrates another new aspect of EVA in the future, operation near high-power-generating solar array systems, where charging is known to occur and arc discharges have been observed. An example is the 50 KW system NASA is planning for the Space Station. Solar array segments have differences in electrical potential due to the series-parallel interconnection of individual cells. Point to point arc discharges occur when the difference in potential between the most positive and most negative solar cells, or from the solar cells to the ambient plasma, is too large (Stevens, ref. 8). The net effect of the solar array surfaces is to modify the nearby plasma such that a hazard may be created for a free-flying astronaut. A solar array hazard would have a major impact on EVAs anticipated during assembly and operations of a Space Station dependent on solar arrays.

AURORAL OVAL ENVIRONMENT

The concept of the auroral oval was developed by Feldstein and Starkov (ref. 9) but has been most strikingly illustrated by the recordings of auroras made by satellite imaging systems. Originally, the oval was used to describe the location where optical auroras were observed. Later, it has also been found useful in describing other phenomena, including the precipitation of energetic electrons which produce auroras. The oval extends completely around the earth although, in some orientations, observation of optical auroras is masked by sunlight. The auroras are found in a band, somewhat circular in form, with its center displaced towards the night side of the earth. It has a greater latitudinal extent on the dark, or midnight, side. The oval forms a fixed pattern, relative to the sun, which changes in geographical location as the earth rotates beneath (Whalen, ref. 10).

The satellite auroral photos in figure 5 demonstrate how the aurora can have spatial variations, particularly in north-south extent (Pike, ref. 11). Local midnight is at the center of each of the 2 auroral photos. On the right, when the aurora would be described as quiet, the aurora has a narrow latitudinal extent. A spacecraft crossing it at right angles would be exposed to energetic auroral electrons for only a few seconds. As the angle between the orbit and the narrow auroral arc decreases, the time of exposure increases. An orbit tangent to a relatively narrow auroral arc could result in exposure to energetic auroral electrons for tens of seconds, even when the aurora is not disturbed. The left half, from a different orbit of the same satellite, shows that the aurora has a wider latitudinal extent during a geophysical disturbance and, depending on the exact orbit, the spacecraft would encounter the energetic auroral electrons for tens or even hundreds of seconds. A lengthy exposure to energetic electrons is not required in order to have a spacecraft charge to dangerous voltage levels.

A DMSP satellite has been measured to charge to hundreds of volts within seconds (Burke and Hardy, ref. 12). The effect of extended exposure time is to increase the likelihood that the auroral oval would be disturbed during the passage of the spacecraft.

The temporal variation of auroras in the oval is also of interest in evaluating the likelihood of interaction effects on EVA equipment. Auroras are the most variable and the most intense during worldwide magnetic storms following solar flares. Auroral temporal variations are important even at other times. To see this, All Sky Camera (ASCA) pictures taken with a 160 degree field of view fisheye lens from the AFGL Airborne Ionospheric Observatory will be used. The aircraft flew a path with a ground track in geographic coordinates as shown on the left in figure 6 (Krukonis and Whalen, ref. 13). Because the earth rotated as the aircraft flew west, the aircraft remained near local magnetic midnight. The same flight path in the corrected geomagnetic local time and latitude coordinate system is shown on the right. The aircraft flew short north and south tracks, approaching and departing from the magnetic pole. The ASCA field of view covered 4 degrees of magnetic latitude to the north and to the south; therefore, 70 degrees north corrected geomagnetic latitude was always within view.

Each strip of the ASCA montage for this flight, figure 7, shows 30 pictures taken once per minute with a 15 second time exposure. The complete montage represents a continuous 9 hour time history of the temporal variations of the aurora near local magnetic midnight. Each circular image has been rotated during reproduction so that North is to the left and East is at the top. This improves interpretation of the images by removing effects from changes in the heading of the aircraft. At times, the sky was almost clear of auroras with only faint forms not easily seen in these reproductions. At other times, optical auroras covered the field of view from the northern to the southern limits, about 900 kilometers. The energetic electron deposition region producing the optical auroras corresponds closely with the optical aurora. Spacecraft, including a free-flying astronaut, would have been in the area of precipitating particles likely to cause charging for over 100 seconds. It is also important to realize how quickly the upper atmosphere can change from showing only faint traces of aurora to bright auroras covering the ASCA field of view. This can be seen near 0310 UT when the aurora expanded from a narrow feature near the southern horizon to completely fill the field of view within 2 to 3 minutes. This is much too fast for the astronaut to take any action towards protecting himself. Operational planning must consider that the astronaut will find himself immersed in the energetic auroral electron stream. The EVA equipment must not be susceptible to adverse environmental interactions due to energetic auroral electrons.

The values of the Q, AE, and Kp magnetic indices (Mayaud, ref. 14) measured by magnetic observatories during the flight are shown on the right. It is inappropriate to attempt extensive conclusions about the correlation of magnetic index variations with the ASCA montage for this small quantity of data. The magnetic index Q represents the disturbance from quiet day values in a 15 minute period for an auroral oval magnetic observatory, in this case Sodankyla in Sweden. The 2 values are for the first and second half of each row of images. The index Q has been found to be correlated with the location of optical auroras (Feldstein and Starkov, ref. 9). For this data sample, it increased generally as the auroras became brighter and filled more of the ASCA image.

The value for AE represents the hourly average of the AE index determined for a global network of auroral oval observatories. AE represents the sum of the eastern and western auroral electrojets and increases as the magnitudes of optical auroras increase (Allen et al, ref. 15). In addition to the hourly AE averages, the AE graphical plot showed maxima of 400 gammas at 0330 UT, 425 gammas at 0410 UT, 550 gammas at 0730 UT, and 640 gammas at 1050 UT. These maxima can be associated with brighter image sequences in the figure. In addition, the times which show smaller, fainter auroral images, 05 to 06 UT and 09 to 10 UT, have lower average AE values.

This data sample provides a good example for comparing optical auroral images with the Kp index. The Kp index represents the variation of magnetic activity for low latitude observatories during a 3 hour period. The bright sequence from 0310 UT to 0400 UT and the faint sequence from 0450 UT to 0555 UT are both associated with the 03 to 06 UT value of Kp of 4. This example demonstrates the limitations of using a 3 hour index like Kp to characterize a phenomenon, such as the optical aurora, which can vary greatly within the 3 hours.

GEOPHYSICAL CONDITIONS ENCOUNTERED DURING SKYLAB EXTRAVEHICULAR ACTIVITY

As mentioned previously, Skylab had a 50 degree inclination. Its orbit intersected the auroral oval when the orbital latitude extremes occurred: at longitudes where the magnetic poles are closest to the equator; and, near corrected geomagnetic local midnight when the auroral oval reached its most equatorward extent. The geophysical conditions at the time of the 10 Skylab EVAs have been examined. The closest approach was in the southern hemisphere during the EVA of Garriott and Bean on 22 September 1973, during the Skylab III mission. Partial Skylab ground tracks are shown in figure 8 in the corrected geomagnetic local time and latitude coordinate system. The auroral oval for a Q value of 2 (the value measured at Sodankyla at the same time) is shown. The closest approach was on orbit 2022, where the minimum separation was about 5 degrees of latitude. A 5 degree latitude separation usually means complete absence of the precipitating energetic electrons which are present in the auroral oval. The end of EVA at 1400 UT on orbit 2023 is actually repressurization, meaning that the astronauts were already inside the airlock. This analysis shows that EVA within the aurora is something that the United States has yet to encounter.

SUMMARY

Our preliminary analysis of the special situation of free-flight EVA from the Shuttle while passing through the auroral oval has identified it as a space system environmental interaction deserving of further study. Further investigations by the Air Force and NASA have not resolved this concern. AFGL is continuing to work with NASA scientists to determine if a hazard does exist, how serious it is, and whether it is life-threatening. Discussions have been held with the NASA JSC Crew Equipment Division responsible for developing the astronaut equipment, to bring to their attention that charging and arc discharges may occur on the equipment surfaces. Once the charging hazard has been defined, then the susceptibility of the existing and future systems can be determined by engineering tests. AFGL believes it is prudent and necessary to establish what will happen so that, as shown in figure 9, EVA will continue to be successful as the Shuttle flight envelope expands to orbits through the auroral oval.

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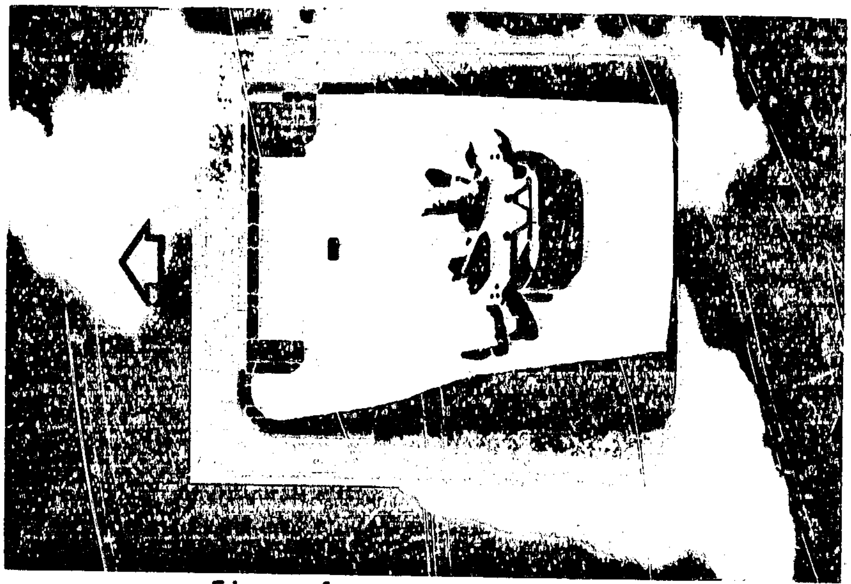

Figure 1. - Polar orbit EVA.

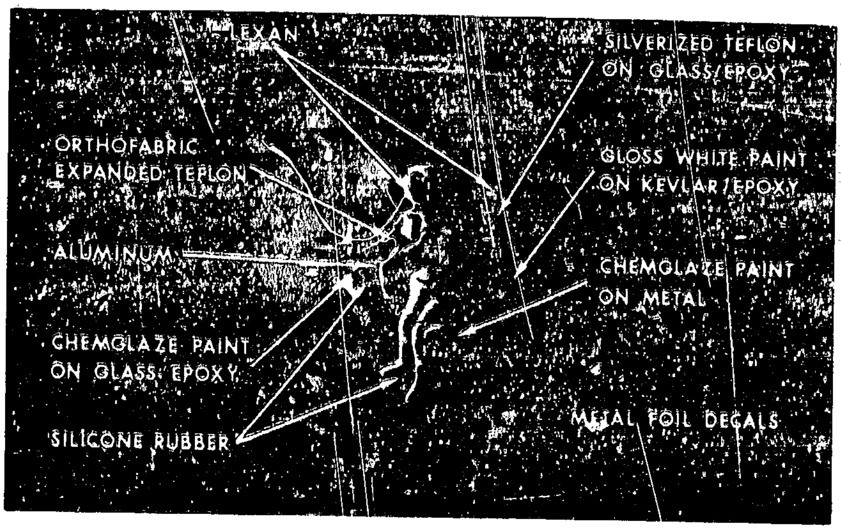

Figure 2. - Astronaut equipment materials.

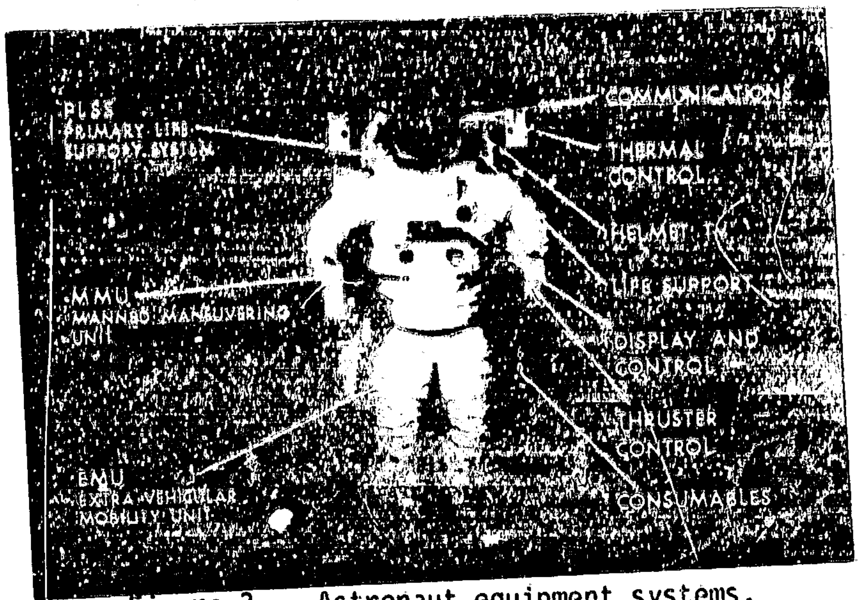

Figure 3. - Astronaut equipment systems.

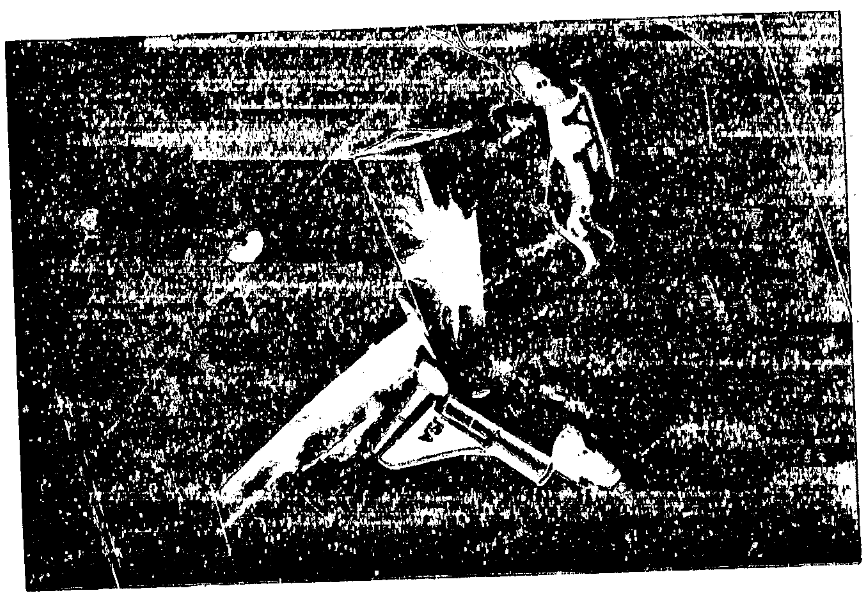

Figure 4. - Astronaut and solar power systems.

Figure 5. - Aurora.

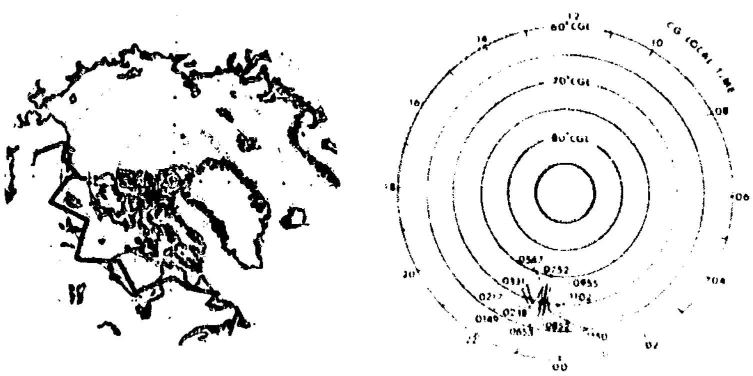

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Figure 6. - AFGL Airborne Ionospheric Observatory flight tracks.

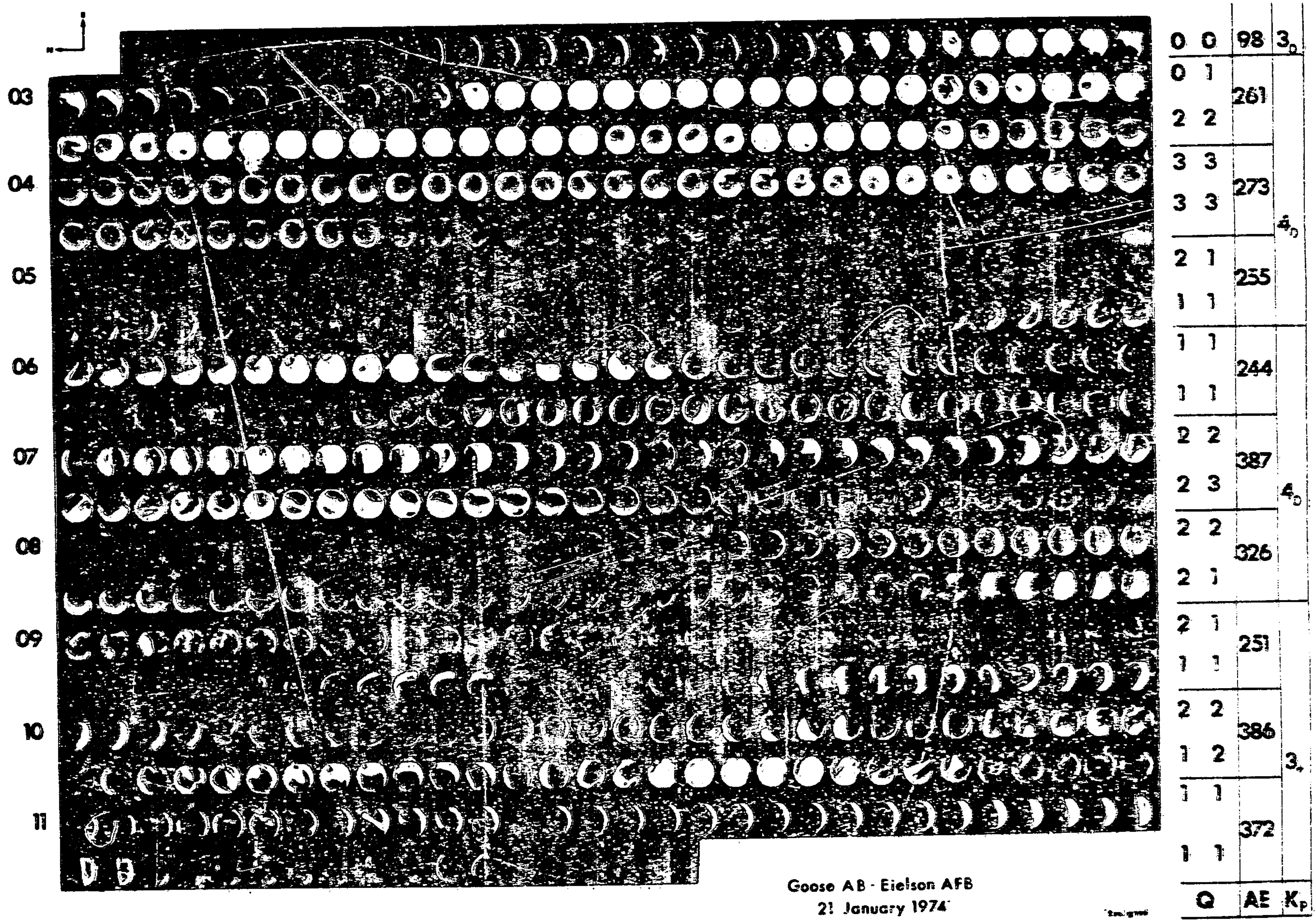

Figure 7. - ASCA Montage.

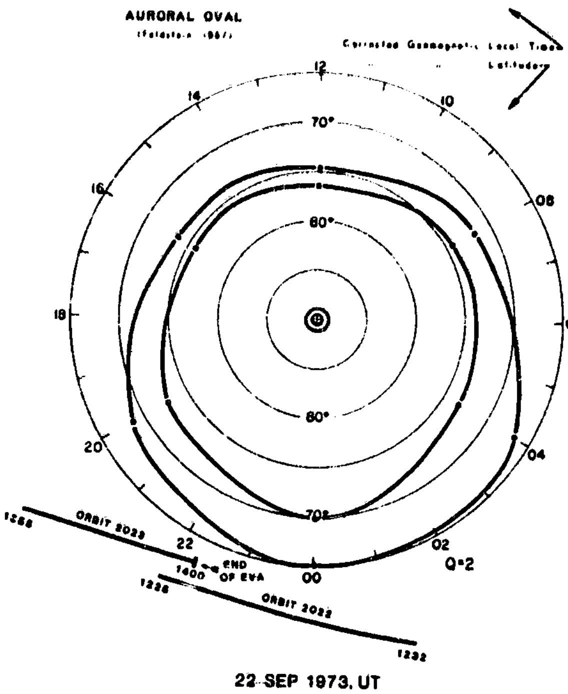

Figure 8. - Skylab subsatellite ground tracks.

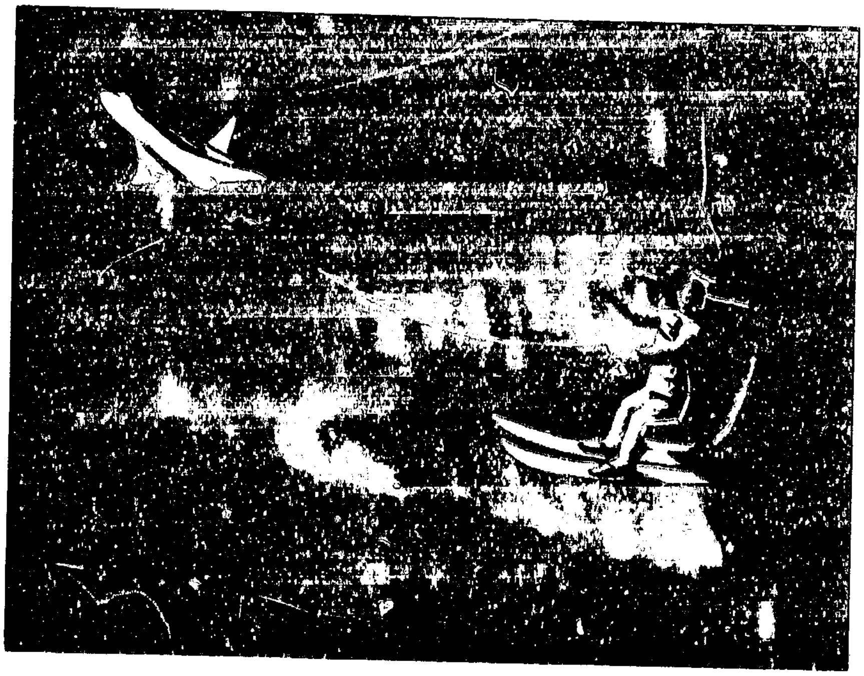

Figure 9. - Future polar orbit extravehicular activity.