N71-22492

NASA CONTRACTOR REPORT

NASA CR-61346

NATURAL ENVIRONMENT SUPPORT FOR SPACE SHUTTLE TESTS AND OPERATIONS

By E. A. Carter

Lockheed Missiles and Space Company
Huntsville Research and Engineering Center
Huntsville, Alabama

April 13, 1971

Prepared for

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

1. Report No. NASA CR-61346	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle NATURAL ENVIRONMENT SUPPORT FOR SPACE SHUTTLE TESTS AND OPERATIONS		5. Report Date April 13, 1971
		6. Performing Organization Code
7. Author(s) E. A. Carter		8. Performing Organization Report No.
9. Performing Organization Name and Address Lockheed Missiles and Space Company Huntsville Research and Engineering Center Huntsville, Alabama		10. Work Unit No.
		11. Contract or Grant No. NAS8-20082
		13. Type of Report and Period Covered CONTRACTOR REPORT
12. Sponsoring Agency Name and Address NASA Washington, DC 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Technical Coordinator: S. C. Brown, Aerospace Environment Division, Aero-Astrodynamics Laboratory, Marshall Space Flight Center, Alabama

16. Abstract

This document is presented in two chapters. Chapter I (nine sections) describes the purpose and basis for the document and the methods and facilities expected to be available by 1977 to meet the methods and facilities expected to be available by 1977 to meet the Natural Environment Support requirements necessary to support the space shuttle tests and operations. Sections 3 through 7 discuss the natural environment interface of the phases of a mission from preliminaries and prelaunch through final approach and landing. Section 8 proposes advanced design and operations concepts which warrant careful consideration and advance planning and development to achieve minimum sensitivity to the natural environment. Section 9 presents the conclusions.

Chapter II, in five sections, corresponding to the phases of a mission, lists a number of events throughout the mission that are sensitive to the natural environment. It describes the observations, predictions, and communications support required to minimize concern and optimize mission success. Chapter II also provides details which will be useful in programming facilities as the space shuttle operations evolve.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Natural Environment, Space Shuttle, Interface, Tests, Operations, Support Requirements	Unclassified-Unlimited E. D. Geissler Director, Aero-Astrodynamics Laboratory

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
UNCLASSIFIED	UNCLASSIFIED	101	$3.00

*For sale by the Clearinghouse for Federal Scientific and Technical Information Springfield, Virginia 22151

Section 1
INTRODUCTION

This document estimates and describes the natural environment support which will be required for the space shuttle tests and operations, based on current knowledge of the space shuttle system. In preparing the document, the space shuttle concept as it is currently envisioned was analyzed in detail, and some events in the natural environment that may in some ways affect the program were identified. The basic NASA and Air Force philosophy is to develop the space shuttle with minimum sensitivity to the natural environment. To achieve this goal the interface with the natural environment must be thoroughly understood and natural environment requirements identified for the space shuttle. Early identification of the natural environment support requirements is essential.

This document is designed to be flexible so that as the space shuttle test and operation concepts evolve and as progress is made in natural environment support capabilities, it can be easily amended to reflect these changes and to continue its usefulness into the period of full space shuttle operation. The work is based on the best current estimate of the space shuttle program and capabilities for natural environment support projection through 1980.

Only certain space shuttle events that interface with the natural environment and provide an estimate of the degree of involvement are considered. Specific operations will require tailoring the natural environment support available to specific operational locations which have not yet been selected. When the space shuttle program is more firmly defined, this document may be used to determine support requirements at specific locations.

Currently, the development test period is planned for 1973 to 1976; ten operational test vehicles will be utilized in the period 1977 to 1980, and the program will become operational by 1980. The developmental tests which will also be used during operational tests are considered in this document, but purely developmental tests, such as model testing, air drop testing, etc., are not included. Lockheed recommends that a separate document be prepared to support developmental tests.

Section 2 of this document (Chapter I) is a discussion and a listing of natural environment support that is available or is expected to become available by 1977 to meet space shuttle requirements. The support may not be available at the required location but it should be considered as a proven concept requiring only application as needed. Sections 3 through 7, which discuss the natural environment requirements for various phases of the mission from preliminary and prelaunch operations through the entire mission to landing, demonstrate how the natural environment support must be considered. Section 8 proposes potential design and operations concepts requiring continuous development and monitoring to assure that natural environment support and technology advance with the space shuttle requirements. Section 9 presents the conclusions resulting from the analysis.

Chapter II lists in detail the environment-sensitive space shuttle events and describes the natural environment interface. These events are expected to change as the space shuttle program evolves. Known changes are solicited to help keep this document current.

Reliability values given in this document can be considered as root mean square (RMS) deviations about a mean value, which is the best estimate of the measure of the quantity.

Section 2

NATURAL ENVIRONMENT SUPPORT AVAILABLE AND EXPECTED TO BE AVAILABLE BY 1977

The types of natural environment support that could be used to meet space shuttle requirements are introduced in this section. Although the information is as complete as possible at this time, a specialist in the specific support required should be consulted for optimum use of resources (Refs. 1 through 5).

Support services are generally available from the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service or for military requirements from the Department of Defense, Air Force Air Weather Service, from the U.S. Army (who provide their own weather service for research and development), and from the U.S. Navy (who have a weather service to meet their requirements). Other Government agencies such as the U.S. Coast Guard, the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA) and others have the capability to meet their own requirements when the service is not otherwise available. Numerous private companies also provide specialized weather service, studies, and research and development to meet new requirements. Most foreign countries also have a central weather service.

2.1 SURFACE OBSERVATIONS

2.1.1 Wind Observations Near the Surface

Wind measurements near the surface or on towers are usually recorded with wind vanes and cup or impeller anemometers. Standard instruments are reliable to 3 degrees direction and 1.0 m/sec in the usual wind values. Instru-struments used for range support will provide frequency response up to 2 Hz and 80% amplitude resolution. Special low mass anomometers measure three components of the winds at very low wind speeds. Hot wire anemometers are quite accurate, but they are delicate, and their use is generally limited to wind tunnels and laboratories. Sonic anemometers have been developed for special uses but the additional cost must be considered for the additional accuracy gained. The near-surface wind requirements are usually met with vertical and horizontal arrays of standard wind equipment. The wind data may be transmitted immediately to control centers and recorded on magnetic tape. There is also a completely mechanical device which will record the "maximum wind" during a given time period.

2.1.2 Temperature and Humidity

Temperature and humidity are usually considered together because humidity is quite meaningless without temperature. Both are easily obtained with standard equipment. Relative humidity and absolute humidity are often confused. Relative humidity is the most easily obtained and is popularly referred to as "humidity." It is expressed in percent and represents the percent of water vapor in the air compared to how much water vapor that the air could hold, with 100% being the saturation point. Absolute humidity is the ratio of the mass of water vapor present to the volume occupied by the moist air mixture; that is, the density of the water vapor component. Absolute humidity is usually expressed in grams of water vapor per cubic meter or, in engineering practice, in grains per cubic foot. When temperature and pressure are known, either type of humidity can be computed from the other. When effects on equipment are considered, the absolute humidity is a more reliable indicator of the amount of water vapor that is available to react with metals or other chemicals.

Temperature and humidity can be determined by a psychrometer — wet- and dry-bulb thermometers — which, when they are properly ventilated, indicate the thermodynamic wet- and dry-bulb temperatures of the atmosphere from which relative or absolute humidity can be determined. Temperature measurements are reliable to about $0.3^{\circ}C$ and a relative humidity of 3%.

Several temperature and dewpoint measuring sets are on the market which will give continuous readings of temperature from a thermocouple or a resistor and dew point from a chemical solution or from a cooling module and a sensing mirror to measure when condensate forms. These temperature reliabilities are about 0.5°C for temperature and 1°C for dew point. These readings can be "remoted," transmitted to a control center and recorded on magnetic tape. A hygrothermograph consists of a strip chart on a drum, usually timed for 8 days, with a temperature pen arm operated by a bimetallic strip or a bourdon tube and a humidity pen arm operated by a hair hygrometer. These readings are not considered accurate, however, unless they are frequently calibrated.

2.1.4 Visibility

Visibility has traditionally been a measure of the distance that objects can be distinguished in daylight or lights can be seen at night. A transmissometer has been developed which measures the transmissivity of light, usually in the range of 100 m to 3 km. This transmissivity has been empirically equated to visibility. Reliability is approximately 10% for visibilities up to 5 times the length of the baseline. The system is unreliable for visibilities greater than 5 times the baseline. The "slant-range visibility," a value of direct relation to aircraft landings, is not easily observed. Some attempts have been made to calculate slant-range visibility from surface visibility and cloud heights but these have not been reliable. Types of precipitation and condition of the windshield may be significant. Transmissometer readings may be remoted, recorded and retransmitted.

2.1.5 Cloud Heights

Cloud heights are most frequently estimated by a trained observer. Certain mechanical and electronic aids have been developed. A cloud ceiling is defined as the height at which 6/10 or more of the sky is obscured. Both ceiling height and visibility equipment must be supplemented with visual observations to be completely reliable. Equipment to assist in measuring cloud height consists of constantly rising balloons (5 mps) for daytime use and at night a ceiling light beam with a theodolite or clinometer to measure the angle of inclination of the light spot on the cloud base from which the cloud heights are easily computed. These methods are reliable up to 1 km. Several types of cloud height sets are in use which have a visible or infrared beam and a detector to measure the light spot on the cloud and to compute cloud heights automatically. Readings can be as frequent as every 3 seconds. Readings are provided either day or night and reliability is 10% up to six times the base line (usually 122 m). A vertical pointing radar may be used to detect clouds, which can frequently provide bases and tops of up to three layers of clouds. The measurements of cloud heights can be remoted and transmitted to a control center and recorded on magnetic tape.

2.1.6 Radar Storm Detectors

Radar storm detectors operating at wavelengths of about 3.2, 5.3 or 10.3 cm can detect clouds to a maximum range of 400 km, depending on the moisture content of the clouds and type of radar used. With this equipment, buildup, movement and dissipation of fronts, squall lines and isolated rain showers and thunderstorms can all be detected. The complete data are stored by video tape. Digital storage and readouts of the scope patterns are possible but these generally are not satisfactory.

2.1.7 Remote Automatic Weather Observing Stations

Remote automatic weather observing stations (land and ocean buoy) are available, which encompass all of the items of equipment used in taking and recording the surface observation. They operate unattended up to two weeks, or longer with a reliable power source. Improvements are expected to be made by 1977 in the remote operations of observing equipment.

2.1.8 Electrostatic Potential

Electrostatic potential is measured by a radioactive device to determine the electric field intensity at a point on the earth. The principle of operation of the radioactive device assumes that the ionization of the air close to the conductor is partly carried away by the field or is returned to the sensor, depending upon polarity, until an equilibrium current flow is established by the atmospheric field. The output is used to calculate the potential gradient. A corona current detection station for indicating high atmospheric potential gradients is located in conjunction with the radioactive devices. The corona current detector, basically a one-meter whip antenna connected to a micro-microammeter measures the corona current leakage caused by large fields present at the detector. The information is available in real time (Refs. 6-8).

2.2 UPPER AIR OBSERVING EQUIPMENT

2.2.1 Wind Observations above the Surface Layer

Winds above the surface layer are observed by noting the motion of objects in the atmosphere as accurately as possible. The use of rising balloons which are tracked by one or two theodolites when they are visible, and by radar or radio direction finding equipment, is the most widely used method. A radiosonde suspended from a balloon transmits frequencies that are converted to pressure, temperature and humidity versus altitude and time. The complete observation from the surface until balloon burst, frequently about 30 km, is called a RAWINSONDE observation. A radar reflective balloon, which is tracked with a precision radar, provides the most precise wind profile to about 18 km. A roughened balloon is used to prevent or control vortex shedding, with resultant decrease in aerodynamic motion. A widely used sensor is a super pressure-roughened balloon about 2 m in diameter, called a "Jimsphere." Balloons designed to float at constant altitude can be placed in the atmosphere and tracked for several days. Aircraft measure the wind speed and direction at flight altitude and the resultant wind over some distance is made available. Meteorological rockets launched to altitudes of 65 to 100 km may eject radar chaff, falling spheres or a sounding instrument. The most common rocket-sonde provides information from which winds, temperature, pressure and density are computed from about 65 km to 25 or 30 km at which points the data are compared with radiosonde data. Special sensors are used in the upper atmosphere (see paragraph 2.3.5). Many special high-atmosphere and near-earth probes have provided some wind data in this region. Exploration, equipment and data are expected to become routine above the 65 to 70 km altitude currently achieved and to increase our knowledge of the upper atmosphere greatly in the next few years.

2.2.2 Temperature and Humidity

Temperature and humidity in the upper atmosphere are reported routinely by radiosonde observations (the thermodynamic data from the RAWINSONDE). Moisture decreases below the threshold of routine detection at about 12 km. Special observations have measured moisture above this level but the amount is not considered significant for space vehicle operational support requirements. Temperature, however, can be measured or computed from nearly all probes discussed under wind observations. Temperature and humidity can be measured from a tethered balloon which is allowed to ascend to about 300 m and then recovered. Temperature and humidity are also frequently available from aircraft observations. Some specially equipped reconnaissance aircraft may drop sensors known as dropsondes from which profiles from flight level to the surface of temperature, humidity and pressure are computed from radio signals transmitted to the aircraft.

2.2.3 Pressure

Pressure in the upper atmosphere is measured with an aneroid cell and an arm which is activated by the aneroid to sweep across electrical contacts, causing signal transmissions that can be interpreted as pressure. Data are reliable to about 0.2% to 1.0%, depending on height, up to 10 mb. Above 10 mb a hypsometer uses the principle of the variation with altitude of the boiling point of a liquid (carbon disulfide) to measure atmospheric pressure. The barometer or hypsometer is part of the sounding equipment described previously.

2.2.4 Airborne Radar Storm Detection Equipment

Radar storm detection equipment, especially designed for airborne operation, is often carried aboard aircraft. These observations or scope readings are usually available only to the flight crew and little use is made of them after their immediate use. Special reconnaissance aircraft may photographically record scope pictures of major storms or hurricanes but retrieval of the data is quite difficult.

2.2.5 Weather Satellite Observations

Weather satellite observations have provided global cloud cover photographs for about 10 years. The program has not yet achieved its full operational capability, but much useful data have been collected. Today's satellites have an Automatic Picture Transmission (APT) capability which transmits the picture it sees as it passes overhead. About three pictures (5000 km long and 2500 km wide) can be received in one pass before the satellite is out of range. More detailed pictures are taken as directed, stored and transmitted to a control station on demand. The satellite has an infrared picture-taking capability, and the full potential of satellite observations is just beginning to be realized. Much progress is anticipated in the next few years.

2.3 SPACE ENVIRONMENT OBSERVING EQUIPMENT

2.3.1 Earth's Magnetic Field

The earth's magnetic field is measured by a magnetometer network which measures geomagnetic variation. Variations of the geomagnetic data furnished by the network are related to temperature and density variations at the altitudes of low earth satellites. A large solar flare can cause immediate disruption of communications systems due to emission of ultraviolet and x-ray energy. This activity is followed, in 30 minutes to an hour, by high energy protons, called cosmic rays. About two days later the solar protons and electrons emitted from the flare reach the earth's atmosphere, causing magnetic and ionospheric storms. The magnetometer readings provide a quantitative indication of atmospheric and electron density changes to be expected a few hours after the onset of the magnetic storm.

2.3.2 Ionospheric Soundings

Ionospheric soundings (ionograms) up to the F_2 layer (about 300 km) provide indications of disturbed conditions caused by solar flares or magnetic storms and information concerning the propagation for HF radio communications systems in the region sampled. The ionospheric sounder consists basically of a pulse transmitter, a wide-band receiver, a read-out and a power supply. The equipment determines, as a function of frequency, the virtual heights and electron densities of reflecting layers in the ionosphere up to the layer of maximum electron density (F_2 layer).

2.3.3 Cosmic Radio Noise

The relative intensity of cosmic radio noise received at the earth's surface is measured by an instrument called a riometer. The cosmic radio noise is absorbed or attenuated as it passes through the ionosphere and the amount of attenuation depends upon the density of charged particles in the ionosphere. These measurements are useful for detecting solar flare activity and related changes in ionospheric density, and for predicting long-range communications conditions.

2.3.4 Neutron Monitor

A neutron monitor is an equipment system which uniquely detects those secondary neutrons and protons which are produced as a result of collisions of high energy protons with air molecules in the earth's upper atmosphere. The high energy protons, which are emitted from solar flares, have energies greater than 4000 million electron volts (meV). Information concerning the occurrence of high energy protons is useful for providing warnings to manned space activities, and for predicting subsequent variations in the density, electron density and magnetic field strength. The equipment consists of a series of Geiger tubes surrounded by lead and polyethylene.

2.3.5 Rocketsonde and Upper Atmosphere Rocket Probes

Rocketsonde and upper atmosphere rocket probes are made on an experimental and test basis. Winds, temperature, pressure and density are measured quite frequently from RAWINSONDE altitudes (30 km) to about 65 km. With slightly larger rockets the data can be extended from 65 km to about 90 km. Above 90 km, different techniques must be used and with larger rockets, the costs increase rapidly. Rocket probes with mass spectrometers to detect the composition of the upper atmosphere have been used experimentally. Data are gathered by these techniques from about 120 km to about 155 km with some measurements as high as 320 km (Ref. 9).

2.3.6 Densities at Satellite Altitudes

Densities at satellite altitudes (140 km and above) are computed from orbit trajectories. A drag coefficient of the satellite is computed or assumed, and the orbital decay is a function of the density. Densities at these altitudes are also measured by satellite-borne accelerometers and mass spectrometers.

2.3.7 Solar Activity

Solar activity is observed by a solar optical telescope system to maintain continuous visual and photographic surveillance of the solar atmosphere. Also a radio telescope can be used, consisting basically of an antenna and a receiver. The unit of measurement for radio frequencies associated with solar flares is antenna temperature in degrees Kelvin. The radio frequency emission from the sun may increase by several orders of magnitude during a large solar flare. The receiver amplifies only those signals in a certain band of frequencies.

2.4 PREDICTION CAPABILITIES

Because prediction capabilities have many variables and prediction results are controversial, they are discussed here only in generalities. In addition to the natural environment variables, such variables as the time interval involved, the lead time, the detail desired, the information available and the options available influence a successful prediction capability. There is some capability, however limited, to predict all of the natural environment items discussed herein. Tradeoffs have successfully been reached in the past between observing, engineering and predicting. This document is the initial step to explore ways to again successfully achieve this balance and to identify the actions to follow in the intervening years.

Nearly all prediction methods require that past occurrences be extensively investigated. Some patterns become apparent (such as seasonal weather conditions and the solar activity cycle), but as more and more detail is required about the future, the more chance there is that some unknown factor will modify the pattern. In the upper atmosphere, data are just becoming available so that as these data are analyzed and more data gathered, it is reasonable to expect that upper atmosphere predictions will improve more rapidly than those for the lower atmosphere. Also, additional papers on upper atmosphere and space predictions are becoming available (Ref. 11).

In the lower atmosphere, many years of records of environmental data are available which provide a complete description of past occurrences, so that there is now available a nearly complete description of atmospheric phenomena which may be expected to occur in the future as well as a close estimate of the frequency of expectation of certain criteria. To assure that operations are within the design capability of equipment, the chances of a phenomenon occurring must be traded off against the cost and feasibility of designing for that criterion. Secondly, a capability must be developed to assure that, operationally, the established space shuttle design criteria and operational constraints are not exceeded (Ref. 12). This is accomplished by (1) carefully measuring the phenomenon; (2) communicating data to control authority along with adequate prediction and warning that the operation is on a collision course with the environment; and (3) directing alternate options that are available. This document is designed to program the capability to assure that there are sufficient available options to complete the space shuttle missions safely.

Section 3

DISCUSSION OF SERVICE REQUIRED FOR PHASE I EVENTS – PRELIMINARIES AND PRELAUNCH

Preliminaries for the first flights will include considerable developmental testing. The preliminary events for which a standardized natural environment support service appears desirable are included here. Preliminary events which are limited to development and are not expected to be repeated in the operational tests are omitted. It is recommended that this service be described in a developmental test natural environment support document. Since the booster and orbiter are reusable, all events which occur after a landing from a previous mission, are included in the preliminaries and prelaunch phase for the next mission. All listed events may not occur during each sequence but the support must be available. The preliminaries are considered as events which take place before the booster and orbiter are erected for mission launch. There are no firm lines between events, and service for any one event may be available from service provided other events, but for each mission sequence there must be a conscious effort to provide for service required, so that lead times are properly anticipated and milestones are successfully achieved. Events may range from a decision to proceed or to alter or cancel the mission because of a condition of extreme emergency. By meeting the requirements for each event, the natural environment service support is expected to develop into a smooth-flowing, available, service operation which can be applied as needed for the success of the mission.

The events for which natural environment service requirements are specified are listed in Table 3-1. Events 1 through 11 are generally considered in preliminary events but some of them must also be considered in prelaunch. Events 12 through 21 are milestones in the prelaunch countdown. Generally these requirements are patterned after experience gained from Saturn V-Apollo missions (Ref. 13).

Table 3-1

PHASE I EVENTS – PRELIMINARIES AND PRELAUNCH

1. Storage of equipment
2. Surface transportation of equipment
3. Air transportation of equipment
4. Static tests of booster and orbiter individually and booster and orbiter mated
5. Abatement and control of impurities in exhausts
6. Acoustic propagation and noise abatement
7. Flight tests of booster and orbiter, horizontal takeoff, <u>subsonic cruise</u> and return, manned or unmanned
8. Flight tests of booster and orbiter, horizontal takeoff, <u>transonic</u> and return, manned or unmanned
9. Flight tests of booster and orbiter, horizontal takeoff, transonic, <u>supersonic</u> and return, manned or unmanned
10. Flight tests of booster, vertical takeoff, manned or unmanned.
11. Self-ferry flight capability, booster and orbiter, horizontal takeoff and horizontal landing.
12. Emergency egress, on-ground or in-vertical launch configuration
13. Mating booster and orbiter for launch
14. Exposure of vehicles in launch position
15. Prelaunch preparation
16. Deflection of vehicles in launch position
17. Fuelling booster and orbiter in launch position
18. Passenger loading and crew loading
19. Supply loading
20. Launch abort
21. Decisions to launch

3.1 PRELIMINARIES

The preliminaires are considered as events which may take place at any place in the world, although generally within the 50 states.

The surface extremes which must be considered are described in Refs. 14 and 15. References 16 and 17 describe the toxic fuel hazards. Section 2, and Refs. 14 through 17 provide the background necessary to meet the support requirements in Events 1 through 6.

Events 7 through 11 constitute the flight events in the preliminaries. Although most of this support is derived from experience gained in supporting high performance and supersonic aircraft, there are unique support requirements which should be considered.

a. "Flight Following" should be used for all initial flights. This consists of a team of atmospheric specialists who analyze every detail of the atmosphere to be encountered in the proposed flight path and continually update their information and analysis as the mission progresses. Additional information continually becomes available and the progress of the mission itself verifies and assists in projecting information for the remainder of the mission.

b. Advance reconnaissance should be used, particularly if any severe weather or critical air turbulence (CAT) is even remotely anticipated. At the present time predictions of CAT are not reliable.

c. Consideration should be given to placing atmospheric sensors on the reconnaissance vehicles and possibly on the flight vehicle to telemeter data to the control center.

d. Data and communications capability should be combined into an automatic alert capability so that if the predicted environment is being, or about to be exceeded by certain limits, the mission is automatically altered or directed to be altered.

e. It appears that landing and the surface environment will be a critical part of each flight, as is now the case with high performance aircraft. In addition, the limited fuel will restrict the alternate landing sites that are available. Proper reconnaissance, flight following, alerting and alternate courses available will adequately meet this requirement.

3.2 PRELAUNCH

The prelaunch events 12 through 20 are a series of countdown events in which a hazardous environment might cause delays or serious damage. Event 21 requires an advance prediction for the entire mission.

Events 12 through 20 repeat experiences which were encountered in Saturn V countdown. However, the environment service is expected to be more exacting for the space shuttle mated vehicle. The vehicle is expected to be on the launch pad up to two weeks. There are unique support requirements to be considered during this period.

a. The wind profile from the surface to about 150 m is required. The observations for this profile are best made from a meteorological tower near the launch complex. Also on-pad measurements near the top and base of the vehicle are minimum requirements. Predictions must be made for the entire preparation period with the extreme conditions expected to be provided from climatological records. Continuous predictions up to 72 hours must be made so that precautions can be taken if certain limits are exceeded.

b. The temperature profile from the surface to about 150 m is required. The basic profile may be taken from sensors on a meteorological tower, but additional measurements are needed from the surface of the vehicle to compute vehicle bending (due to thermal stresses); and temperatures are needed from inside the vehicle for compartment and equipment temperatures.

c. Measurements must also be made of humidity and other impurities which may cause deterioration of equipment with repeated use.

d. Items associated with storms must also be monitored and predicted. Storm radar is currently the best aid for short term predictions (up to three hours) for storms. Specific items to monitor and predict for storms are winds, hail, electric potential, precipitation, hydrometeors and cloud cover. Increased use of satellite pictures must be made to help interpret storm movement and intensity.

In event 21, decisions to launch are made continually, based on the complete spectrum of information that this document is designed to make available. There will be certain milestones throughout the mission when this decision will be reviewed. At that time all items in this document for which some foresight is available should be presented. Particular emphasis must be placed on all items which will be critical prior to the next review period. Some decisions will irrevocably commit certain events. The predictions for these events must be carefully prepared and clearly presented. Although the space shuttle is planned to become a routine operation, the decisions to proceed with each mission must guard against apathy and such checks should be included in the standardization procedures. Automatic warnings and safeguards must be built into the system to prevent proceeding until all natural environment items have been considered.

Section 4

DISCUSSION OF SERVICE REQUIRED FOR PHASE II EVENTS – LAUNCH TO ORBIT

The natural environment for the launch-to-orbit phase must be well understood when the final decision to launch is made. The operations events which interface with the natural environment and the means of providing the required service are detailed in Volume II of this document but they are summarized here. The events are listed in Table 4-1. They fall easily into four groups. Events 1 through 5 involve the liftoff and lower atmosphere flight. Events 6 through 9 involve the transition portion of the flight (above 10 km). Events 10 through 13 involve the booster flight and return. Events 14 through 17 involve the orbiter-only flight into earth orbit. The service requirement is based on Saturn V-Apollo experience and much more is expected to be learned during space shuttle developmental tests.

4.1 LIFTOFF AND LOW ATMOSPHERE FLIGHT

Events 1 through 5 require thorough observation, analysis and prediction of the lower atmosphere (up to 10 km) as it involves the vehicle. In addition to routine data, there are unique support requirements which must be considered.

a. The detailed wind profile from the surface to 150 m can be measured from sensors on a meteorological tower located in the launch complex. In addition it is necessary to have wind sensors on the launch tower, which are required to monitor the effect of the wind on the vehicle to trace the booster exhaust cloud.

b. The wind and temperature profile from the surface to 30 km, obtained from weather charts and from RAWINSONDE and FPS-16 Radar/Jimsphere observations are required. Winds to 3 km are required for emergency abort, and to 6 km for acoustic propagation.

c. Special equipment is required to obtain information of the electrostatic potential between the earth and the atmosphere.

d. Aerial reconnaissance of cloud conditions should be available and used as necessary. Very high level reconnaissance from U-2 type aircraft with sensors telemetering data and transmitting pictures to the control center may be desirable.

Table 4-1

PHASE II EVENTS — LAUNCH TO ORBIT

1.	Booster ignition, liftoff and tower clearance
2.	Pollution from booster exhaust
3.	Emergency egress during liftoff, booster and orbiter
4.	Climb through clouds, booster and orbiter mated
5.	Emergency abort during climb, booster and orbiter
6.	Transonic flight, booster and orbiter mated
7.	Dynamic pressure transition, booster and orbiter mated
8.	Transition through maximum winds
9.	Booster and orbiter separation
10.	Booster reentry
11.	Booster aerodynamic flight down to 3 km altitude
12.	Booster approach, 3 km to 300 meters altitude
13.	Booster landing, 300 meters altitude to surface
14.	Orbiter ignition
15.	Orbiter powered ascent
16.	Orbiter enter orbit
17.	Abort prior to orbit

4.2 TRANSITION FLIGHT

Events 6 through 9 require detailed analysis of the atmosphere for the transition portion of the flight. Unique support requirements must be considered.

a. Winds, specifically from near the surface to about 20 km, must be in as much detail as possible to predict the effects of maximum dynamic pressure, transonic flight and any wind shears over the length of the vehicle. Currently the FPS-16/Jimsphere is recognized as the best system to obtain detailed wind information in this region.

b. Booster and orbiter separation (about 75 km) may demand special requirements. Details are not known at this time.

4.3 BOOSTER FLIGHT AND RETURN

Events 10 through 13 require as much information as possible about the atmosphere from separation to the surface, for booster return. The booster must be capable of returning to the launch site or to an alternate return site. The return path must be determined prior to launch. There is probably some, but little chance to alter the return path. In addition to routine data there are unique support requirements to consider.

a. Rocketsonde and radiosonde observations at locations along the return path may be desirable.

b. Aerial reconnaissance of the return path should be available if necessary, for detection of severe weather and CAT.

c. The booster or orbiter should have the capability for atmospheric sensing and telemetering data to the control center so that any information gained from the ascent flight which may be significant can be used for the return flight.

d. Approach and landing requirements will be similar to high performance aircraft and detail requirements will be determined during booster test and ferry flights. (See paragraph 3.1.2).

4.4 ORBITER FLIGHT AND ORBIT

Events 14 through 17 require space environment information. Because this is a new requirement with only limited manned space travel for experience, all possible support requirements must be considered carefully.

a. Requirements for reentry and abort prior to entering orbit must be programmed at the time of the launch decision. Support requirements will be similar to the booster return but a completely different path may be used. A global, dynamic atmospheric model would be desirable to determine the natural environment along abort and return paths.

b. Transition to space environment requires knowledge of the solar influence in space. Specific measurements required: density at altitudes of low earth satellites; variations of geomagnetic data from a magnetometer network; electron densities in the ionosphere; high energy protons and secondary neutrons and protons; solar optical and solar radio telescope data for measurements of solar activity. It is anticipated that space observations will provide much improved space data over that presently available from ground stations.

c. A continuous monitor and warning system for meteors and meteorites must be provided.

Section 5

DISCUSSION OF SERVICE REQUIRED FOR PHASE III EVENTS – ORBIT MANEUVERS AND OPERATIONS

The natural environment for space operations for low earth orbit satellites must be continually monitored for known hazards such as effects of solar activity, meteors and meteorites and also because of lack of experience for any unknown, unforeseen or unanticipated hostile environment. The events are listed in Table 5-1.

Table 5-1

PHASE III EVENTS – ORBIT MANEUVERS AND OPERATIONS

1.	Burn to change orbits
2.	Burn and connect with space station
3.	Emergency requiring EVA
4.	Transfer to space station
5.	Reload orbiter
6.	Orbiter separate from space station

The following support should be considered.

a. The solar activity and its effects on the space environment must be monitored by solar and radio telescopes both on earth and from manned or unmanned satellites.

b. Activity in the ionosphere can be monitored with a vertical-incidence ionospheric sounder to determine, as a function of frequency, the virtual heights and electron densities of reflecting layers in the ionosphere up to the layer of maximum electron density (F_2 layer).

c. Solar particles can be detected with a neutron monitor to detect high-energy solar protons (about 400 MV) and secondary neutrons and protons. A riometer can be used to detect slower moving low-energy particles (50 MV) which arrive about four hours after the high-energy protons.

d. Measurements of variations in geomagnetic data from satellite data or from a magnetometer network are required.

e. The densities at the orbital altitudes are necessary.

f. Meteor and meteorite showers must be traced through space and their approach to the earth's orbital altitudes must be anticipated.

g. Various activities in the orbital environment might require different criteria for each of the above items but each of them must be monitored and predicted for each event and limiting criteria established.

h. A most unique requirement of the orbital environment dictates "a continuous watch for the unusual." Admittedly, experience in orbital environment cannot be gained until more of it has been encountered. Therefore, continued vigilance for harbingers for the unusual may avert serious situations.

Section 6

DISCUSSION OF SERVICE REQUIRED FOR PHASE IV EVENTS – DEORBIT AND REENTRY

Once the reentry sequence is started, events are irrevocable to landing. There are some alternate options available so the events where alternate courses may be taken are listed separately (Table 6-1). Events 1 through 5 are mostly within the influence of space environment. Items 6 through 8 are transition to atmospheric environment and item 9 is transition to cruise altitude.

Table 6-1

PHASE IV EVENTS – DEORBIT AND REENTRY

1. Selection of landing site
2. Burn for reentry
3. Burn to brake for reentry
4. Reentry down to 120 km altitude
5. Reentry 120 to 90 km altitude
6. Reconfirm landing site
7. Reentry 90 to 60 km altitude
8. Reentry 60 to 30 km altitude
9. Reentry 30 to 3 km altitude; cruise altitude is about 4 km

6.1 DEORBIT AND REENTRY TO 90 KM ALTITUDE

The decision to return requires the selection of a return path and a suitable landing site. Firm criteria for pre-deorbit knowledge of atmospheric densities along the return path have not yet been determined. Selection of the return time and landing site requires prediction of the entire return process. While there is a narrow reentry angle dependent on the atmospheric density, the density does not vary sufficiently to require changes in the reentry angle.

6.2 REENTRY 90 TO 30 KM ALTITUDE

There are two unique requirements during the 90 to 30 km altitude descent.

a. At about 60 to 80 km altitude, the vehicle will pass through a layer where maximum reentry heating will take place. The heating will be dependent on the atmospheric density and density gradient. Currently there is comparatively little data from infrequent rocket-sondings in this region. Special rocketsonde observations and a global atmospheric model are possible solutions currently under study to gather information in this region.

b. The radius of action of the vehicle for alternate landing site options decreases with decreased altitude so the wind drift and information for acceptable landing conditions become critical during this descent.

6.3 REENTRY 30 TO 3 KM ALTITUDE

The orbiter transitions to cruise flight at about 4 km altitude. During this portion of descent the vehicle becomes committed to a definite landing region. Unique requirements to help select this region must be considered.

a. The wind profile from 30 km altitude to the surface may be determined from RAWINSONDE observations and upper air charts. The wind data should have an automatic input to the control center, either on board or on ground, to arrive at the desired locations along the descent path.

b. Aerial reconnaissance to detect and report severe weather and CAT in advance of the vehicle may be necessary.

c. The terminal conditions for landing are available from observing equipment at the potential landing sites and short range predictions. These should have automatic inputs so that at reaching the 3 km altitude level a "fail safe" landing site is available.

Section 7

DISCUSSIONS OF SERVICE REQUIRED FOR PHASE V EVENTS – APPROACH AND LANDING

The final approach has two emergency requirements to meet. The approach from 3 km altitude and landing is planned to be either a ground-controlled or a pilot controlled approach and landing. Category II landing minimums are specified as ceiling >100 ft altitude and visibility $>1/4$ mi horizontal. The approach and landing events are listed in Table 7-1. Unique natural environment service must be considered.

a. The two emergencies are events 2 and 4, which involve one go-around either from 65 meters altitude, or from 300 meters altitude with one engine out. It is assumed these may be under instrument conditions so knowledge of precipitation and turbulence in the landing pattern is required.

b. The requirement for ground-controlled landing or pilot-controlled landing requires that terminal conditions, i.e., ceiling, visibility and winds be telemetered to the ground controller and the pilot.

c. The runway conditions are important for landing roll and braking. The runway conditions are determined by visual inspection and testing.

Table 7-1

PHASE V EVENTS – APPROACH AND LANDING

1. Approach, 3 km to 300 meters altitude
2. Go-around at 300 meters with one engine out
3. Final approach
4. Go-around from 65 meters altitude
5. Touchdown, landing roll and braking

Section 8
POTENTIAL DESIGN AND OPERATIONAL CONCEPTS FOR MINIMUM ENVIRONMENTAL INTERFERENCE

This section is intended to provide new and advanced concepts in natural environment support to meet the demanding requirements of space shuttle development and operation. Although all of the concepts discussed here may not become reality, they must be conceived now in order for them to evolve and become an integral part of space shuttle operations. The final products in a few years may not be like the descriptions given here but they do point out areas where presently conceived equipment or procedures either do not exist or are not adequately integrated to space shuttle development. By recognizing these areas early, and by making a conscious effort to foresee and meet requirements for each item, progress in natural environment support can be kept parallel with space shuttle development.

8.1 MINIMUM ENVIRONMENTAL INTERFERENCE

A new concept is proposed in which the design and operational system takes into account the fact that there are certain extreme, natural environmental phenomena which will be hazardous or disastrous to a mission if they are encountered. Extreme conditions or potentially extreme conditions occur only a small percentage of the time, and the vehicle operates only a small percentage of the time. In most cases, these extreme conditions can be detected and predicted. For those phenomena which can be detected and predicted reliably, a support system can be developed to ensure that the extreme phenomena are avoided. Development of available design and operational systems for avoiding or "out-smarting" extreme phenomena should result in considerable savings and increased reliability. Although there are many cases where sophisticated methods of detection and prediction will help avoid extreme phenomena, only a few are listed here.

a. Within the footprint available for an orbiter return and land, several suitable landing sites are available. By trade-off of the requirement for a specific return site, one of three landing sites 350 km apart will most assuredly be well above the landing minimums established for one site, thus greatly increasing the safe return possibility with perhaps less instrumentation. Alternate return paths will provide options to avoid CAT, thunderstorms and other extreme phenomena.

b. Reentry paths which will avoid extreme horizontal density gradients may be designed to ensure that vehicle heating remains well below that which would be encountered in an extreme density gradient.

c. Because extreme occurrences in the space environment are not known, it is axiomatic that design requirements cannot give any degree of assurance of extremes, therefore, design to certain limits and warnings and protective actions when these limits are approached appear as the best solution.

Some of the other concepts proposed will relate closely to this concept but they are of sufficient importance to warrant separate discussion.

8.2 COMMUNICATIONS INTERFACE

Traditionally there has been a lag in natural environment observations and transmissions to meet the operational requirement, ostensibly for evaluation, analysis or other reasons. In reality the communications have never been designed for real time use of information about the natural environment. It is conceivable that observations and predictions could be telemetered to the control authority (including vehicle commander) and automatically matched with the flight plan so that warnings and alternate options can be implemented.

8.3 FLIGHT FOLLOWING

Flight-following per se is not a new concept but it often becomes routine, thereby defeating its effectiveness. It is proposed that flight-following, as described in paragraph 3.1.2.a, with computer programmed safeguards be utilized. The safeguards would ensure that attention is given to the natural environment details and would warn if checks and update information is not provided as required.

8.4 SPACE WATCH FOR THE UNUSUAL

As described in Section 5, item h, because the space station and orbiter will be operating in an unknown environment in which relatively little operational experience exists, a continuous watch of all environmental data that can be monitored will be necessary. Real time data must be monitored for any unusual readings or groups of readings to try to anticipate hazards, even though the details of the hazards may never before have been detected. This alertness will decrease the chances of new experiences being disastrous and will greatly speed up the detection and consequences of new experiences for subsequent encounters.

8.5 AERIAL RECONNAISSANCE

Aerial reconnaissance must take on a new dimension in real time alerts of certain conditions detected or encountered. Detection of severe weather and CAT must be objective and avoidance action must be immediate. Other atmospheric measurements may be as significant.

8.6 ATMOSPHERIC SENSORS ON BOOSTER AND ORBITER

The installation of critical parameter atmospheric sensors on the booster and orbiter should be considered – remote sensors if they are developed. The data should help warn the vehicle of any deviations from expected conditions. The data should be used in real time for the mission in progress. See Ref. 18 for information on remote sensors. Self-sensing devices may be used for circumnavigating thunderstorms, CAT or other phenomena.

8.7 EQUIPMENT IMPROVEMENT

Sensors for natural environment are continually undergoing improvement. In various places throughout this document weaknesses in equipment are mentioned. Generally they are in rocketsondes, space environment, automation, and communications. Also in the upper atmosphere there will be requirements for measuring new parameters.

8.8 PREDICTION IMPROVEMENT

While prediction improvement is a perennial goal, much improvement is as perennially illusive. Concepts in this document acknowledge these limitations and advocate improvements which are achievable to complement any modest gains in prediction capabilities. Increased knowledge of the natural environment will enhance prediction capabilities, and this knowledge must be continually applied toward this goal.

Section 9
CONCLUSIONS

It is apparent that the existing and anticipated natural environment support capability can adequately be assembled to meet the requirement for space shuttle tests and operations. It is equally apparent that natural environment support must continue to develop parallel with space shuttle development. Specific services which must be developed and tailored to space shuttle concepts are described in Section 8.

As the space shuttle requirements become firm and specific locations are selected for space shuttle operations, the events which will require natural environment support listed in Volume II may be used to define specific requirements. With the natural environment interface requirement in Volume II and the list of services in Section 2, the requirements for each location can be quickly determined with assurance that items have not been overlooked. Persons knowledgeable in various phases of the natural environment support have contributed and reviewed the service outlined. Continued cooperation will ensure that advanced concepts and procedures are entered as they are developed.

Section 10

REFERENCES

1. "Operations of the Weather Bureau," U.S. Department of Commerce, ESSA, Weather Bureau, May 1968 (in 1970 ESSA was renamed National Oceanic and Atmospheric Administration, NOAA, and Weather Bureau renamed: National Weather Service).

2. "Environmental Measuring Equipment Used by Air Weather Service in Support of Air Force and Army Operations," Air Weather Service (MAC), AWS Pamphlet No. 105-3, November 1967.

3. Dalton, Q. S., "Meteorological Instrumentation and Techniques," Test Department, Naval Ordnance Test Station, August 1965.

4. "Proceedings of the IEEE – Special Issue on Remote Environmental Sensing," April 1969.

5. "Weather Meteorological Handbook," Hq. Air Force Eastern Test Range Pamphlet No. 105-1, January 1965.

6. Daniels, Glen E., "Atmospheric Electricity Criteria Guidelines for Use in Space Vehicle Development," NASA TM X-64549, August 1970.

7. "Analysis of Apollo 12 Lightning Incident," NASA, MSC 01540, February 1970.

8. Schuknecht, L. A. and E. A. Carter, "Analysis of the Atmospheric Environment at Cape Kennedy, Florida, for Criteria Related to the Hazard of Atmospheric Electrical Activity," Lockheed Missiles & Space Co., LMSC/HREC D162126, February 1970.

9. Schaefer, E. J., "Temperature and Composition of the Lower Thermosphere Obtained from Mass Spectrometer Measurements," Dept. of Aerospace Engineering, High Altitude Engineering Laboratory, The Univ. of Mich., Ann Arbor, Michigan.

10. Hartman, G. and D. Muller, "A Determination of the Helium and Nitrogen Content of the Lower Thermosphere (110-155 km) above Ft. Churchill, Canada," Federal Ministry for Scientific Research, Research Report No. W68-54, Bonn, West Germany, August 1968.

11. Moe, Kenneth and Nancy V. Crooker, "Prediction of Geomagnetic Activity," McDonnell Douglas Astronautics Company, NASA Contractor Report No. 61306, August 1969.

12. "Study Control Document Space Shuttle System, Program Definition (Phase B)," Section II, Appendix C, NASA, 15 June 1970.

13. "Apollo-Saturn V PSRD," as revised, Meteorological Programmed Support Requirement Document, NASA, MSFC, S&E-AERO-Y.

14. "Ground Atmospheric Extremes, NASA Space Vehicle Design Criteria, Environmental Volume," in process of publication.

15. Daniels, Glenn E., Editor, "Terrestrial Environment (Climatic) Criteria Guidelines for Use in Space Vehicle Development, 1969 Revision," NASA TMX-53872, Second Printing March 15, 1970.

16. Dumbauld, R.K., J.R. Bjorklund, H.E. Cramer, and F.A. Record, "Handbook for Estimating Toxic Fuels," GCA Corporation, NASA Contractor Report 61326, April 1970.

17. Thayer, S.D., M.W. Chandler and R.T. Chu, "Rise and Growth of Space Vehicle Engine Exhaust Associated Diffusion Models," NASA Contractor Report 61331, July 1970.

18. "Proceedings of the IEEE, Special Issue on Remote Environmental Sensing," Institute of Electrical and Electronics Engineers, Inc., Vol.57, No.4, April 1969.

19. IRIG Document 110-70, "Reliability of Meteorological Data."

CHAPTER II

Section 1

PHASE I EVENTS — PRELIMINARIES AND PRELAUNCH

Operations Event I-1	Natural Environment Interface Requirements
☐ Storage of Equipment	Observations: Temperature, temperature change, compartment temperatures and absolute humidity are important. Special observations may be required in assembly and storage areas. Occurrence and risks from storms, including lightning, should be determined.
	Predictions: Climatology provides adequate information on which to base storage decisions.
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Normal communications are adequate
	Comments: The types and concentrations of atmospheric impurities and constituents and their interaction with equipment are important. In outside storage protection from hail and other hydrometeors is necessary.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event I-2	Natural Environment Interface Requirements
☒ Surface Transportation of Equipment	**Observations:** Weather extremes, including storms may be hazardous to surface transportation.
	Predictions: Twelve-hour predictions are required and this is a caution event because accurate twelve-hour predictions are not sufficiently reliable and may not be for the time periods considered
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Storm information is not adequately disseminated for surface transportation. The National Weather Service high frequency net is designed to help this problem, but progress should be monitored.
	Comments: Special precautions are required to prevent unexpected changes in pressure, temperature and humidity. Sealed compartments must be able to withstand pressure changes between high and low elevations, build up from increased temperatures and condensation resulting from decreased temperatures.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event I-3	Natural Environment Interface Requirements
☒ Air Transportation of Equipment	Observations: Normal air traffic observations are required. In addition, this is a caution event because observations of Critical Air Turbulence (CAT) are not adequate. Storms, clouds, in-flight conditions, winds, CAT, landing conditions (ceiling, visibility, winds, conditions of runway, icing)
	Predictions: Predictions for the time of the flight plus 2 hours (about 6 hours) are required for all items listed under observations. Improvements in predicting CAT are desirable.
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Normal in-flight communications are adequate.
	Comments: Special precautions are required to prevent unexpected changes in pressure, temperature and humidity. Sealed compartments must be able to withstand pressure changes between high and low elevations, build up from increased temperatures and condensation resulting from decreased temperatures.
Code: ☐ Inconvenience ☒ Caution X Safety	

Section 1

PHASE I EVENTS – PRELIMINARIES AND PRELAUNCH

1. Storage of Equipment
2. Surface Transportation of Equipment
3. Air Transportation of Equipment
4. Static Tests of Booster and Orbiter Individually and Booster and Orbiter Mated
5. Abatement and Control of Impurities in Exhausts
6. Acoustic Propagation and Noise Abatement
7. Flight Tests of Booster and Orbiter. Horizontal Take-Off, Subsonic Cruise and Return. Manned or Unmanned
8. Flight Tests of Booster and Orbiter. Horizontal Take-Off, Transonic and Return. Manned or Unmanned
9. Flight Tests of Booster and Orbiter. Horizontal Take-Off, Transonic, Supersonic and Return. Manned or Unmanned
10. Flight Tests of Booster. Vertical Take-Off. Manned or Unmanned
11. Self-ferry Flight Capability, Booster and Orbiter. Horizontal Take-Off and Horizontal Landing
12. Emergency Egress. On-Ground or In-Vertical Launch Configuration
13. Mating Booster and Orbiter for Launch
14. Exposure of Vehicles in Launch Position
15. Prelaunch Preparation
16. Deflection of Vehicles in Launch Position
17. Fuelling Booster and Orbiter in Launch Position
18. Passenger Loading and Crew Loading
19. Supply Loading
20. Launch Abort
21. Decisions to Launch

PHASE I EVENTS – PRELIMINARIES AND PRELAUNCH

Operations Event I-4	Natural Environment Interface Requirements
X Static tests of booster and orbiter individually and booster and orbiter mated	Observations: Micro-observations from surface to 150 meters altitude, winds, temperature, skin temperatures, compartment temperatures and electric potential. Storm observations including freezing, electric potential and hail are required. Storm radar observations required.
	Predictions: Climatology is used for risk hazards, this is a safety event because predictions are required continuously and lead time is that required to take necessary precautions. Improvement in forecasting is desirable.
Developmental Tests 1973-1976 Operational Tests 1977-1980	
	Communications: Special Communications are required to gather the observed data at the prediction location and disseminate the predictions to the test manager. Communications should be automated as much as possible.
	Comments: The special observations and communications must be designed into the test facility.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event I-5	Natural Environment Interface Requirements
☒ Abatement and control of impurities in exhausts.	Observations: Surface conditions – winds, temperature, humidity and monitoring of impurities are required. Aloft – winds and lapse rate are required to 1 km altitude. Preliminary release, tracing and monitoring of a harmless cloud may be desirable.
	Predictions: Three-hour predictions of items listed under observations are required. Present methods and accuracies are adequate. Prediction of the exhaust cloud path for up to six hours is required.
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	Communications: Normal communications are adequate.
	Comments: State of the art is adequate to trace the exhaust and predict concentrations of impurities but this is a caution event because pollution laws and concern are becoming more important.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE I EVENTS – PRELIMINARIES AND PRELAUNCH

Operations Event I-6	Natural Environment Interface Requirements
☐ Acoustic propagation and noise abatement.	Observations: Surface: micro winds surface to 300 meters, temperatures, humidity. Aloft: wind, temperature and humidity profiles to 6 km.
	Predictions: Twenty-four hour predictions of wind and temperature profile to 6 km altitude required. Acoustic propagation prediction program required.
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	Communications:
	Comments:
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE I EVENTS – PRELIMINARIES AND PRELAUNCH

Operations Event I-7	Natural Environment Interface Requirements
X Flight tests of booster and orbiter. Horizontal take-off, subsonic cruise and return. Manned or unmanned	Observations: Surface: winds, clouds, visibility, hydrometeors, runway temperature, slant range visibility, storm radar. Aloft: winds, clouds, temperatures, CAT, and aerial reconnaissance.
	Predictions: Predictions for the duration of preparations and the flight time plus two hours are required for all items listed under observations. Improvements in predicting CAT are required.
Development Tests 1973-1976 Operational Tests 1977-1980	Communications: Special communications are required and must be designed as the tests are being designed. Present methods of relaying landing information to the pilot or controller are inadequate. Fully automatic relay is desired.
	Comments: The subsonic cruise, particularly unmanned must have a way to avoid or circumnavigate thunderstorms.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event I-8	Natural Environment Interface Requirements
X Flight tests of booster and orbiter. Horizontal take-off, transonic and return. Manned or unmanned. This is concerned only with transonic portion of flight — for other portions see I-7, 9.	Observations: In transonic portion of flight detailed observations of winds, temperatures, clouds, hydrometeors, computations of density, CAT are required. Aerial reconnaissance is required. Temperature and wind profile from surface to flight altitude is desirable. Predictions: Three-hour predictions of items listed in observations are required. A prediction for sonic boom propagation is required.
Developmental Tests 1973-1976 Operational Tests 1977-1980	Communications: Special automatic air-to-ground communications are required. Air-to-air communications are required with the reconnaissance vehicle. Comments: While special precautions are required for the first flights, some of these may not be required after more information becomes available and when procedures are standardized.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event I-9	Natural Environment Interface Requirements
X Flight tests of booster and orbiter. Horizontal take-off, transonic, supersonic and return. Manned or unmanned. This is concerned only with supersonic portion of flight — for other portions see I-7, 8.	Observations: In supersonic portion of flight detailed observations of winds, temperatures, clouds, hydrometeors, CAT, and computations of density are required. Aerial reconnaissance is required. Temperature and wind profile from surface to flight altitude is desirable. Predictions: Three-hour predictions of items listed in observations are required. A six-hour prediction for sonic boom propagation is required along the supersonic flight path.
Developmental Tests 1973-1976 Operational Tests 1977-1980	Communications: Special automatic ground-to-air communications are required. Air-to-air communications are required with the reconnaissance vehicle. Comments: Special precautions because of the "sonic boom" may be required but they are unknown at this time.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE I EVENTS – PRELIMINARIES AND PRELAUNCH

Operations Event I-10	Natural Environment Interface Requirements
X Flight tests of booster, vertical take-off, manned and unmanned.	Observations: Micro-observations from the surface to 150 meters altitude. Winds, temperature, skin temperatures, compartment temperatures and electric potential. Storm observations including freezing, electric potential and hydrometeors are required. Storm radar observations required. Aloft: Detailed wind profile, surface to 18 km altitude required. Aerial reconnaissance required, including CAT. Predictions: Predictions of items listed under observations are required for the period the vehicle is in position and wind shears during the lift-off and climb.
Developmental Tests 1973-1976 Operational Tests 1977-1980	Communications: Telemetering of wind from the base and top of the vehicle to the launch controller is required. Comments: The launch may be controlled from the pilot in the vehicle or from a controller supervising the launch.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event I-11	Natural Environment Interface Requirements
X Self-ferry flight capability, booster and orbiter. Horizontal take-off and horizontal landing.	Observations: Normal air traffic observations are required. In addition this is a safety event because observations of CAT are not adequate. An aircraft preceding the ferry vehicle may be required. Storms, clouds, in-flight conditions, winds, CAT, landing conditions (ceiling, visibility, winds, runway conditions, icing) Predictions: Predictions for the time of the flight plus 2 hours (about 6 hours) are required for all items listed under observations. Improvements in predicting CAT are required.
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	Communications: In addition to normal in-flight communications, special flight-following is required during the test period (1977-1980). Comments:

Code:

☐ Inconvenience

☒ Caution

X Safety

PHASE I EVENTS – PRELIMINARIES AND PRELAUNCH

Operations Event I-12	Natural Environment Interface Requirements
X Emergency egress. On ground or in vertical launch configuration.	Observations: Surface wind conditions and wind profile to 150 meters altitude are desirable.
	Predictions: Two-hour predictions are required for items listed under observations.
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Telemetered wind data to the departure control is required.
	Comments: It is not known if egress will be by ejection or manual. This assumes ejection. Manual has no special requirements.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE I EVENTS – PRELIMINARIES AND PRELAUNCH

Operations Event I-13	Natural Environment Interface Requirements
X Mating booster and orbiter for launch	Observations: Surface: micro-winds surface to 150 meters altitude, storms, radar, electric potential, temperatures, hydrometeors.
	Predictions: Prediction of items listed under Observations for the duration of the event plus two hours are required.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Normal communications are adequate. Telemetered wind observations with warning signals would be desirable.
	Comments: Uneven temperatures may distort the vehicles and mating connections.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event I-14	Natural Environment Interface Requirements
☒ Exposure of vehicle in launch position	Observations: Surface: micro-winds surface to 150 meters altitude, temperatures, skin temperatures, compartment temperatures, humidity, hydrometeors. Storm observations including freezing, electric potential, and hail are required. Storm radar observations required.
	Predictions: Climatology is used for risk hazard greater than 5 days. Long range forecasts for 3 to 5 days and operational forecasts for up to 72 hours. Improvement in forecasting is desirable.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Normal communications are adequate. Telemetered surface observations with warning signals at established criteria would be desirable.
	Comments: The exposure period is not known at this time. It is expected to vary depending on the mission. It will be less than two weeks. Many events take place during the exposure period which make the vehicles more or less vulnerable.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event I-15	Natural Environment Interface Requirements
☒ Prelaunch preparations	Observations: Surface: micro-winds surface to 150 meters altitude, temperatures, skin temperatures, compartment temperatures, humidity, hydrometeors. Storm observations including electric potential and hail are required. Storm radar observations required.
	Predictions: In addition to the predictions for exposure, special events will require more detailed forecasts for special criteria at times when the vehicles are more vulnerable.
Operational Tests 1977-1980 Operations 1980 and Beyond	Communications: Normal communications are adequate. Telemetered surface observations with warning signals at established criteria would be desirable. It should be possible to change the warning criteria easily for short periods.
	Comments: As certain work is being done in the prelaunch process the vulnerability of the vehicle to the natural environment will change. The natural environment warning system must be responsive to these needs.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event I-16	Natural Environment Interface Requirements
☒ Deflection of vehicles in launch position.	Observations: Surface: micro-winds surface to 150 meters altitude, temperatures, skin temperatures, temperature gradient surface to 150 meters altitude. Storm radar observations are required.
	Predictions: Predictions of winds, temperatures and cloud cover for twelve hours in advance are required.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Normal communications are adequate. Telemetered surface observations with telemetered warning signals are desirable.
	Comments: The vehicle may be deflected by winds and uneven temperatures on the skin. Support structures may need to be adjusted or moved.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE I EVENTS – PRELIMINARIES AND PRELAUNCH

Operations Event I-17	Natural Environment Interface Requirements
X Fuelling booster and orbiter in launch position. Operational Tests 1977-1980 Operations 1980 and Beyond Code: ☐ Inconvenience ☒ Caution X Safety	Observations: Surface: micro-winds surface to 150 meters altitude, temperatures. Storm observations including electric potential and hydrometeors are required. Storm radar observations are required. Predictions: Predictions of winds, temperatures and electric potential for the duration of the event plus two hours are required. Communications: Normal communications are adequate. Telemetered winds, temperatures and electric potential would be desirable. Comments:

Operations Event I-18	Natural Environment Interface Requirements
X Passenger loading and crew loading	**Observations:** Surface: micro-winds surface to 150 meters altitude, temperatures, passenger and crew compartment temperatures. Storm radar observations are required.
	Predictions: All launch prediction-items should be available at this time. Prediction of items listed under observations until after launch, including any delays, is required.
Operational Tests 1977-1980 Operations 1980 and Beyond	**Communications:** Telemetered surface observations are desirable.
	Comments:
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event I-19	Natural Environment Interface Requirements
☒ Supply loading	**Observations:** Surface: micro-winds surface to 150 meters altitude, temperatures, compartment temperatures.
	Predictions: Predictions of items listed under observations from the decision to load supplies until after launch, including any delays, are required. Predictions of environmental conditions for launch should be available at this time.
Operational Tests 1977-1980 Operations 1980 and Beyond	**Communications:** Telemetered surface observations are desirable. Temperature and humidity from supply compartments should be telemetered to control.
	Comments:

Code:

☐ Inconvenience

☒ Caution

X Safety

Operations Event I-20	Natural Environment Interface Requirements
X Launch abort (prior to completion of countdown)	**Observations:** None required in addition to those required for countdown.
	Predictions: None required in addition to those required for countdown.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Communications are required for real time monitoring of the natural environment for occurrences which may indicate that launch abort or hold is advisable.
	Comments: Launch abort recycles the environmental requirement back through the exposure and prelaunch events.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event I-21	Natural Environment Interface Requirements
X Decisions to launch	**Observations:** Surface: micro-winds surface to 150 meters altitude, temperatures, clouds, visibility, hydrometeors, electric potential, emergency and alternate site data. Aloft: Detailed winds, temperature, humidity, pressure and density — surface to 18 km altitude, CAT, aerial reconnaissance, rocketsondes to 65 km altitude, satellite observations. Storm and radar observations. **Predictions:** Predictions for all items listed under observations are required as far in advance as possible. Requirement starts 72 hours in advance and requires updating until launch.
Operational Tests 1977-1980 Operations 1980 and Beyond	**Communications:** Special communications with forecast and observed data telemetered to the launch controller. **Comments:** The launch decision will be continually revalidated during the final 72 hours. Gathering data is repeated on critical items each time the decision requires revalidation. Predictions for emergency abort and the orbital environment are needed for this decision.
Code: ☐ Inconvenience ☒ Caution X Safety	

Section 2

PHASE II EVENTS - LAUNCH TO ORBIT

1. Booster Ignition, Lift Off and Tower Clearance
2. Pollution from Booster Exhaust
3. Emergency Egress During Lift Off, Booster and Orbiter
4. Climb through Clouds, Booster and Orbiter Mated
5. Emergency Abort during Climb, Booster and Orbiter
6. Transonic Flight, Booster and Orbiter Mated
7. Dynamic Pressure Transition, Booster and Orbiter Mated
8. Transition through Maximum Winds
9. Booster and Orbiter Separation.
10. Booster Re-entry
11. Booster Aerodynamic Flight Down to 3 km Altitude
12. Booster Approach, 3 km to 300 meters Altitude
13. Booster Landing, 300 meters Altitude to Surface
14. Orbiter Ignition
15. Orbiter Powered Ascent
16. Orbiter Enter Orbit
17. Abort Prior to Orbit

PHASE II EVENTS – LAUNCH TO ORBIT

Operations Event II-1	Natural Environment Interface Requirements
X Booster ignition, lift-off and tower clearance	**Observations:** Surface: Micro-winds surface to 150 meters altitude, temperatures, pressure, exhaust velocities, electric potential.
	Predictions: Two-hour predictions of items listed under observations and wind shear are required.
Operational Tests 1977-1980 Operations 1980 and Beyond	**Communications:** Telemetered surface observations to the launch controller are required with warning when established criteria are exceeded.
	Comments: These events are an irrevocable sequence and except for exhaust velocities, the natural environment effects will have been previously considered.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event II-2	Natural Environment Interface Requirements
☐ Pollution from booster exhaust	**Observations:** Surface: micro-winds surface to 150 meters altitude, temperature profile to 150 meters altitude. A trace capability of the exhaust cloud may be required. Exhaust velocities.
	Predictions: Predictions of items listed under observations and a prediction of the exhaust cloud path for up to 6 hours are required.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Normal communications.
	Comments: Remote sensing and tracking of the exhaust cloud may be required.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event II-3	Natural Environment Interface Requirements
X Emergency egress during lift-off. Booster and orbiter.	**Observations:** Surface: micro-winds surface to 150 meters altitude.
	Predictions: Two-hour predictions of low level micro-winds are required.
Operational Tests 1977-1980 Operations 1980 and Beyond	**Communications:** Normal communications are adequate. Telemetered wind profile data directly to an automatic controlled emergency evacuation system would be desirable.
	Comments: The wind profile data would be used only after an evacuation was started, but if started, corrections for winds would have been included.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event II-4	Natural Environment Interface Requirements
☒ Climb through clouds, booster and orbiter mated.	**Observations:** Continuous monitoring of electric potential is required. Detailed wind profile surface to 18 km altitude is required. Prior aerial reconnaissance is required, including CAT observations.
	Predictions: Predictions of all items listed under observations are required at the time launch decisions are made.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Normal communications of observations and predictions to the launch controller is adequate.
	Comments:
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE II EVENTS – LAUNCH TO ORBIT

Operations Event II-5	Natural Environment Interface Requirements
X Emergency abort during climb. Booster and orbiter.	**Observations:** Surface conditions for landing (winds, ceiling, visibility, storms or freezing conditions) must be available from the prime landing site and any alternates which may be selected.
	Predictions: Predictions of conditions listed under observations must have been available with the final launch decision.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Normal communications are adequate. Telemetered landing information to the abort controller would be desirable.
	Comments: It may be possible for the orbiter to abort the mission into an earth orbit. In such case the information required for return will need to be available after one orbit or when the decision is made to return.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event II-6	Natural Environment Interface Requirements
☒ Transonic flight, booster and orbiter mated.	**Observations:** Aloft: Detailed wind profile at altitudes of transonic flight, temperature profile from surface to supersonic flight. Aerial reconnaissance and measurements of CAT at transonic altitudes desirable.
	Predictions: Predictions of items listed under observations are required at times launch decisions are made. Prediction of sonic boom effects is required.
Operational Tests 1977-1980 Operations 1980 and Beyond	**Communications:** Normal communications to launch controller are required.
	Comments: The natural environment requirements will be the same for booster or orbiter transonic flight individually.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event II-7	Natural Environment Interface Requirements
☒ Dynamic pressure transition. Booster and orbiter mated.	<u>Observations:</u> Aloft: Detailed wind profile at altitudes where maximum dynamic pressure is anticipated. Aerial reconnaissance and measurements of CAT at transonic altitudes are desirable.
	<u>Predictions:</u> Predictions of items listed under observations are required at times launch decisions are made.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	<u>Communications:</u> Normal communications to launch controller are required.
	<u>Comments:</u> The natural environment requirements will be the same for booster or orbiter maximum dynamic pressure individually. It is suspected that winds at about 3-4 km altitude may be critical.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event II-8	Natural Environment Interface Requirements
X Transition through maximum winds.	**Observations:** Aloft: Detailed wind profiles from surface to 18 km altitude.
	Predictions: Predictions of detailed wind profiles from surface to 18 km altitude are required when decisions to launch are made.
Operational Tests 1977-1980 Operations 1980 and Beyond	**Communications:** Normal communications are adequate.
	Comments: The level of critical maximum winds is between 8-15 km altitude. Both maximum dynamic pressure and transonic flight are expected at these same levels. Care must be taken to understand the three effects and their relations to each other. Maximum winds are suspected at higher levels (25-30 km) and perhaps other heights. Further investigations are required.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE II EVENTS – LAUNCH TO ORBIT

Operations Event II-9	**Natural Environment Interface Requirements**
☒ Booster and orbiter separation	**Observations:** Aloft: Rocketsonde observations of temperature, pressure, density and wind are desired.
	Predictions: Climatology provides the basis for predictions at these altitudes. Atmospheric models may provide a better understanding at these altitudes. Atmospheric model development should be given a high priority.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Normal communications are adequate.
	Comments:
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event II-10	Natural Environment Interface Requirements
X Booster reentry	**Observations:** Aloft: Rocketsonde observations of temperature, pressure, density and wind are desired. Sensors during the ascent portion of the flight may compute wind and density and automatically provide information for return.
	Predictions: Climatology provides the basis for reentry design and is expected to be adequate for reentry preductions. Atmospheric models under development may provide improvements for reentry predictions.
Operational Tests 1977-1980 Operations 1980 and Beyond	**Communications:** Normal communications are adequate. Perhaps ascent density and wind data would require telemetering to be useful for reentry.
	Comments:
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event II-11	Natural Environment Interface Requirements
☒ Booster aerodynamic flight down to 3 km altitude.	**Observations:** Aloft: Detailed winds, temperature, humidity, pressure and density down to 3 km altitude. Aerial reconnaissance to provide warning of CAT and thunderstorms along flight path surface. Landing conditions for prime and alternate landing sites are required.
	Predictions: Predictions of items listed under observations are required when decisions to launch are made.
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Ground to air communications required. Special telemetered data to booster control from sensors is desirable
	Comments: There may be a requirement for the booster to return unmanned in which case special thunderstorm avoidance will be required.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event II-12	Natural Environment Interface Requirements
X Booster approach 3 km to 300 meters altitude.	**Observations:** Aloft: Detailed wind profile. Aerial reconnaissance to provide warning of CAT and thunderstorms along flight path is desirable. Surface: landing conditions for selected landing site are required.
	Predictions: Predictions of items listed under observations are required when decisions to launch are made.
Development Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Ground to air communications required. Special telemetered data to booster control from sensors is desirable.
	Comments: There may be a requirement for the booster to return unmanned, in which case special thunderstorm avoidance will be required.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE II EVENTS — LAUNCH TO ORBIT

Operations Event II-13	Natural Environment Interface Requirements
X Booster landing 300 meters altitude to surface.	**Observations:** Surface: ceiling, visibility, hydrometeors, winds at landing site.
	Predictions: Predictions of items listed under observations are required when decisions to launch are made.
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	**Communications:** Ground to air communications are required. Special telemetered data to booster control from sensors is desirable.
	Comments:
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event II-14	Natural Environment Interface Requirements
☐ Orbiter ignition	**Observations:** Aloft: Rocketsonde observations of temperature, pressure and density are desired. Sensors on the vehicle to record ambient conditions are desired.
	Predictions: Climatology
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: None
	Comments: Natural environment within climatic extremes is not expected to affect this operation.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE II EVENTS – LAUNCH TO ORBIT

Operations Event II-15	Natural Environment Interface Requirements
☐ Orbiter powered ascent	**Observations:** Sensors on the vehicle to record ambient conditions are desired.
	Predictions: Climatology
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: None
	Comments: Natural environment within climatic extremes are not expected to affect this operation.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE II EVENTS – LAUNCH TO ORBIT

Operations Event II-16	Natural Environment Interface Requirements
☒ Orbiter enter orbit	**Observations:** Sensors on the vehicle to record ambient conditions are desired. Sensors to detect solar radiation are desired. Immediate satellite observations of abort and return sites should be recorded and automatically provide reentry and return environment.
	Predictions: Predictions of solar activity and effects required. Predictions of meteorite effects required.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Space communications required. Telemetering of satellites observed. Landing conditions required to return control.
	Comments:
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event II-17	Natural Environment Interface Requirements
X Abort prior to orbit	Observations: Aloft: A reentry density profile should be stored on ascent for use during abort descent in event return is near ascent path.
	Predictions: Predictions of densities along probable abort path should be stored prior to launch. If a predicted reentry atmospheric model is available it may be stored to select any reentry path.
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	Communications: Space communications may be required to telemeter any emergency density profile for reentry.
	Comments: All information required for emergency must be anticipated and stored for immediate recall. After reentry remainder of return has the same natural environment requirements as normal return.
Code: ☐ Inconvenience ☒ Caution X Safety	

Section 3

PHASE III EVENTS - ORBIT MANEUVERS AND OPERATIONS

1. Burn to Change Orbits
2. Burn and Connect with Space Station
3. Emergency Requiring EVA
4. Transfer to Space Station
5. Reload Orbiter
6. Orbiter Separate from Space Station

PHASE III EVENTS – ORBIT MANEUVERS AND OPERATIONS

Operations Event III-1	Natural Environment Interface Requirements
☐ Burn to change orbits	**Observations:** Solar activity, proton events, magnetic field, meteorite densities.
	Predictions: Predictions of items listed under observations required.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Continuous 2-way space to ground communications required. Telemetering of sensor data to ground control desirable.
	Comments: It is believed that all space environment requirements will have been included in design and operation but all possible factors must be monitored for caution and emergencies.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE III EVENTS – ORBIT MANEUVERS AND OPERATIONS

Operations Event III-2	Natural Environment Interface Requirements
☐ Burn and connect with space station.	Observations: Solar activity, proton events, magnetic field, meteorite densities. Sun angle for maneuver.
	Predictions: Predictions of items listed under observations required.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Continuous 2-way space to ground communications required. Telemetering of sensor data to ground control desirable.
	Comments:
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE III EVENTS — ORBIT MANEUVERS AND OPERATIONS

Operations Event III-3	Natural Environment Interface Requirements
☐ Emergency requiring EVA	<u>Observations:</u> Solar activity, proton events, magnetic field, meteorite densities.
	<u>Predictions:</u> Predictions of items listed under observations required. Also predictions for emergency reentry and landing required.
Operational Tests 1977-1980 Operations 1980 and Beyond	<u>Communications:</u> Continuous 2-way space to ground communications required. Telemetering of sensor data to ground control desirable.
	<u>Comments:</u>
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE III EVENTS – ORBIT MANEUVERS AND OPERATIONS

Operations Event III-4	Natural Environment Interface Requirements
☐ Transfer to space	**Observations:** Solar activity, proton events, magnetic field, meteorite densities.
	Predictions: Predictions of items listed under observations required.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Continuous 2-way space to ground communications required. Telemetering of sensor data to ground control desirable.
	Comments: It is not known how long the orbiter and space station will be connected but is expected to be a minimum of 2 hours and usually 6 to 12 hours.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event III-5	Natural Environment Interface Requirements
☐ Reload orbiter	Observations: Solar activity, proton events, magnetic field, meteorite densities. Satellite observations of return and abort sites should be recorded. Predictions: Predictions of space environment for return required. Predictions of densities along reentry path and abort or emergency paths required. If a predicted reentry atmospheric model is available it may be stored to select any reentry path. Predictions of landing conditions required.
Operational Tests 1977-1980 Operations 1980 and Beyond	Communications: Continuous 2-way space to ground communications required. Telemetering of sensor data to ground and prediction data to orbiter for return desirable. Comments: Primary landing and alternate sites should be selected at this time.
Code: ☐ Inconvenience ☒ Caution X Safety	

Operations Event III-6	Natural Environment Interface Requirements
X Orbiter separate from space station	**Observations:** Solar activity, proton events, magnetic field, meteorite densities, sun angle for maneuver. Satellite observations of return and abort sites should be available. Rocketsonde observations for reentry path are desirable.
	Predictions: Predictions of space environment for return required. Predictions of densities along reentry path and alternate paths required. If a predicted reentry atmospheric model is available, it may be stored to select any reentry path. Predictions of approach and landing conditions required.
Operational Tests 1977-1980 Operations 1980 and Beyond	**Communications:** Continuous 2-way space to ground communications required. Telemetering of sensor data to ground and prediction data to orbiter for return desirable.
	Comments: By this time period it may be possible that reentry density profiles may be determined from the space station.
Code: ☐ Inconvenience ☒ Caution X Safety	

Section 4
PHASE IV EVENTS - DEORBIT AND REENTRY

1. Selection of Landing Site
2. Burn for Re-entry
3. Burn to Brake for Re-entry
4. Re-entry Down to 120 km Altitude
5. Re-entry 120 to 90 km Altitude
6. Reconfirm Landing Site
7. Re-entry 90 to 60 km Altitude
8. Re-entry 60 to 30 km Altitude
9. Re-entry 30 to 3 km Altitude, Cruise Altitude is About 4 km

Operations Event IV-1	Natural Environment Interface Requirements
X Selection of landing site.	**Observations:** Aloft: Density and wind profile along reentry path are desirable. Satellite observations of proposed landing areas should be available. Surface: Ceiling, visibility, winds, hydrometeors, radar observations at proposed landing sites are required. Paths of major storms are required.
	Predictions: Predictions of all items listed under observations for landing time plus 2 hours are required.
Operational Tests 1977-1980 Operations 1980 and Beyond	**Communications:** Continuous 2-way space to ground communications required. Telemetered surface observations to landing control is desirable.
	Comments:
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE IV EVENTS — DEORBIT AND REENTRY

Operations Event IV-2	Natural Environment Interface Requirements
X Burn for reentry	**Observations:** Satellite observations of return and alternate sites should be available. Rocketsonde observations for reentry path are desirable. Detailed wind profile for reentry path is desirable.
	Predictions: Predictions of densities and winds along reentry path and alternate paths required. Predictions of approach and landing conditions required. Prediction of landing footprint based on predicted atmospheric conditions required.
Operational Tests 1977-1980 Operations 1980 and Beyond	**Communications:** Continuous 2-way space to ground communications desirable. Telemetering of sensor data to ground and prediction data to orbiter desirable.
	Comments:
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE IV EVENTS – DEORBIT AND REENTRY

Operations Event IV-3	Natural Environment Interface Requirements
X Burn to brake for reentry	**Observations:** Aloft: Rocketsonde density measurements along reentry path.
	Predictions: Predictions of wind and densities along reentry path required.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Continuous 2-way space to ground communications desirable.
	Comments: This maneuver is not firmly scheduled, but if possible would take place to retard the craft prior to maximum reentry heating.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE IV EVENTS – DEORBIT AND REENTRY

Operations Event IV-4	Natural Environment Interface Requirements
X Reentry down to 120 km altitude.	**Observations:** Densities along the flight path. Density sensors on the orbiter are desirable.
	Predictions: Predictions of densities for deorbit required.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Continuous 2-way space to ground communications desirable.
	Comments: Reentry below 120 km altitude is divided into 30 km altitude increments because some requirements may become more exact as more information is gained.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE IV EVENTS – DEORBIT AND REENTRY

Operations Event IV-5	Natural Environment Interface Requirements
X Reentry 120-90 km altitude.	**Observations:** Densities along flight path if possible. Density sensors on the orbiter are desirable.
	Predictions: Predictions of densities along flight path are required.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Continuous 2-way space to ground communications desirable. Telemetered density data from the orbiter to controller are desirable.
	Comments: This increment is transition from space environment to atmospheric environment. Data are very scarce and large changes are expected.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE IV EVENTS — DEORBIT AND REENTRY

Operations Event IV-6	Natural Environment Interface Requirements
X Reconfirm landing site	Observations: Surface: ceiling, visibility, hydrometeors, winds, radar observations at proposed landing sites are required. Paths of major storms are required.
	Predictions: Predictions of all items listed under observations for landing time plus 2 hours are required.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Continuous 2-way space to ground communications desirable. Telemetered surface observations to landing control are desirable.
	Comments: Reconfirmation of landing site is required prior to communications black out and while all options are still open.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE IV EVENTS – DEORBIT AND REENTRY

Operations Event	Natural Environment Interface Requirements
X Reentry 90-60 km altitude.	Observations: Rocketsonde wind and density measurements along reentry path are desirable (see comments).
	Predictions: Predictions of wind and density along the reentry path are required.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Continuous 2-way space to ground communications desirable. Telemetered density data from the orbiter to controller are desirable. A communications black-out in this region exists with current reentry procedures. It is expected technology will overcome this.
	Comments: Rocketsondes currently do not routinely reach this region but are expected to by the time period involved. Maximum reentry heating is expected about 60-80 km altitude.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE IV EVENTS – DEORBIT AND REENTRY

Operations Event IV-8	Natural Environment Interface Requirements
X Reentry 30-60 km altitude.	**Observations:** Winds and densities along flight path are desirable. Density sensors on the orbiter are desirable.
	Predictions: Predictions of winds and densities along flight path are required.
Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Continuous 2-way space to ground communications required.
	Comments: The levels at which landing options are lost are not known. Continuous update data are required for all remaining landing options.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE IV EVENTS – DEORBIT AND REENTRY

Operations Event IV-9	Natural Environment Interface Requirements
X Reentry 30 to 3 km altitude. Cruise altitude is about 4 km.	Observations: Aloft: Detailed wind and temperature profiles are desired from the primary and alternate landing sites. Clouds and thunderstorms enroute are required. Aerial reconnaissance is desirable. Surface: Ceiling, visibility, hydrometeors and winds at primary and alternate landing sites are required.
	Predictions: Predictions for all items listed under observations for arrival time plus 2 hours are required. Predicted route to avoid thunderstorms is required.
Operational Tests 1977-1980 Operationa 1980 and Beyond	Communications: Continuous 2-way communications between orbiter and ground controller is required. Approach and landing information telemetered to the orbiter is desired.
	Comments: When orbiter descends below 3 km it becomes comitted to one landing location with one go-around capability.
Code: ☐ Inconvenience ☒ Caution X Safety	

Section 5

PHASE V EVENTS - APPROACH AND LANDING

1. Approach, 3 km to 300 meters altitude
2. Go-around at 300 meters altitude with one Engine Out
3. Final Approach
4. Go-aroung from 65 meters altitude
5. Touchdown, Landing Roll and Braking

PHASE V EVENTS — APPROACH AND LANDING

Operations Event V-1	Natural Environment Interface Requirements
X Approach 3 km to 300 meters altitude.	**Observations:** Aloft: Detailed wind and temperature observations are required over the landing site. Cloud layers and thunderstorms are required. Aerial reconnaissance is desirable. Surface: Ceiling, visibility, hydrometeors, winds and runway condition at landing site are required.
	Predictions: Predictions for all items listed under observations for arrival time plus 2 hours are required.
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Continuous 2-way communications between orbiter and ground controller is required. Telemetered landing information to the orbiter is desirable.
	Comments: This event commits the orbiter to one landing site with one go-around capability. Orbiter is designed capable of one go-around at 300 meters with one engine out.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE V EVENTS — APPROACH AND LANDING

Operations Event V-2	Natural Environment Interface Requirements
X Go-around at 300 meters altitude with one engine out.	**Observations:** Aloft at 300 meters: winds, visibility, slant range visibility. Surface: Ceiling, visibility, hydrometeors, winds, runway conditions.
	Predictions: Predictions for all items listed under observations are required.
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: Continuous 2-way communications between orbiter and ground controller is required. Telemetered landing information to the orbiter is desirable.
	Comments: This would be a one-time emergency maneuver with a mandatory landing upon completion of the go-around.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE V EVENTS — APPROACH AND LANDING

Operations Event V-3	Natural Environment Interface Requirements
X Final approach 300 meters altitude to surface.	**Observations:** Surface: Ceiling, visibility, hydrometeors, winds, runway conditions.
	Predictions: Predictions of all items listed under observations are required for landing time plus 1 hour.
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	**Communications:** Continuous 2-way communications between orbiter and ground controller is required. Telemetered landing information to the orbiter is desirable.
	Comments: This event commits the orbiter to one landing site with one go-around capability from 65 meters altitude provided all engines are operating. Orbiter is designed capable of one go-around from 65 meters altitude with all engines operating.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE V EVENTS – APPROACH AND LANDING

Operations Event V-4	Natural Environment Interface Requirements
X Go-around from 65 meters altitude.	**Observations:** Surface: Ceiling, visibility, hydrometeors, winds and runway conditions are required.
	Predictions: Predictions for all items listed under observations are required.
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	**Communications:** Continuous 2-way communications between orbiter and ground controller is required. Telemetered landing information to the orbiter is desirable.
	Comments: This is a one-time emergency maneuver with capability to climb to safe go-around altitude and mandatory landing upon completion of the go-around.
Code: ☐ Inconvenience ☒ Caution X Safety	

PHASE V EVENTS – APPROACH AND LANDING

Operations Event V-5	Natural Environment Interface Requirements
X Touch Down, landing roll and braking	**Observations:** Surface: visibility, cross winds and condition of runway.
	Predictions: Predictions of all items listed under observations are required.
Developmental Tests 1973-1976 Operational Tests 1977-1980 Operations 1980 and Beyond	
	Communications: 2-way communications between orbiter and ground controller is required.
	Comments:
Code: ☐ Inconvenience ☒ Caution X Safety	