OFFICE OF MANNED
SPACE FLIGHT

APOLLO PROGRAM

PROJECT APOLLO
COORDINATE SYSTEM
STANDARDS

JUNE 1965

APPROVED DATA

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

UNITED STATES GOVERNMENT

Memorandum

National Aeronautics and
Space Administration

M-C MA 1461

TO : Distribution

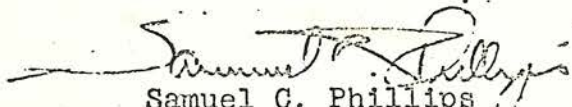DATE: 1 Jun 1965

FROM : Apollo Program Director

SUBJECT: Project Apollo Coordinate System Standards

The document transmitted herewith contains the approved
Coordinate System Standards for the Apollo Program.

The provisions of M-D MB 1400 (Apollo LV and SC Coordinate
Axis and Notation System) dated June 1, 1964 are superseded
by this document and all copies should be destroyed.

The provisions of M-DE 8000.006 (Mass Properties Standard)
dated June 1, 1963 are consistent with this document.

The provisions of AFMTCM 80-4 (Air Force Missile Test Center
Standardized Theoretical Trajectory Magnetic Tape Format)
are unaffected by this document.

Samuel C. Phillips
Major General, USAF

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PROJECT APOLLO COORDINATE

SYSTEM STANDARDS

ABSTRACT

This document contains the Project Apollo Coordinate
System Standards (PACSS). It is the result of the
combined efforts of representatives from GSFC, KSC,
MSC, MSFC and Bellcomm. The standards are primarily
derived from past common practice, provide a high
degree of uniformity and are such that strict con-
formance is technically practical.

The majority of the Standard Coordinate Systems are
associated with the Earth or Moon and have such uses
as site location, ephemerides, trajectory computation
and/or transmittal of trajectory information. The
remaining Standard Coordinate Systems are referenced to
the vehicles (both operating alone and in stacked con-
figurations) or vehicle operations: primarily navigation,
guidance and control. Additionally there are Standard
Relationships which must exist among specific Standard
Coordinate Systems.

All of the Project Apollo Coordinate System Standards
(PACSS) are contained in the Appendices. The text
provides amplification and explanation of the PACSS.

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TABLE OF CONTENTS

1. <u>INTRODUCTION</u>

On June 1, 1964, following more than a year of
intercenter effort, an OMSF directive (M-D MB 1400)
was issued establishing a standard vehicle coordinate
system for Apollo. At the August 1964 Panel Review
Board meeting it was found that the desired standardi-
zation had not in fact been accomplished by this
directive. As a result a new effort was begun in-
volving GSFC, KSC, MSC, MSFC and Bellcomm; the scope
of this effort extended beyond vehicle axes and
included all coordinate systems involved in Apollo
interface data exchange. Complete involvement of
the participating organizations was solicited so
that the resulting standards would be the best
possible set, worthy of unqualified adoption within
Project Apollo and acceptable to all participants.

The resulting Project Apollo Coordinate System
Standards (PACSS)* are contained in this document.
It has been organized such that all PACSS appear in
the Appendices in concise language suited to literal
interpretation. The body of the text attempts to
define the approach and reveal underlying patterns
among the coordinate systems.

In all applications the particular PACSS being used
must be explicitly identified.

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*Users of AMR must submit data to the Range in a
standardized format established by the Air Force
Missile Test Center and described in Reference 1.
These standards, which are outside NASA control,
deviate from the PACSS in several instances.

2. APPROACH

This section is devoted to explaining the methods
employed in the development of the Project Apollo
Coordinate System Standards (PACSS) and thereby
provides a means of understanding the logic of the
approach. Basically a coordinate system provides
a reference frame within which a physical problem
is mathematically formulated and/or data are collected,
analyzed or transmitted. The coordinate system
chosen for use is usually selected based on the
requirements of the specific problem. The Apollo
project may be thought of as a collection of related
problems, each with its own preferred reference
frame. The purpose of this document is to establish
a practical minimum number of well defined coordinate
systems to be used for interface data exchange purposes.
The Approach Diagram on page 3 represents the framework
for the development of the PACSS and is explained in the
following subsections.

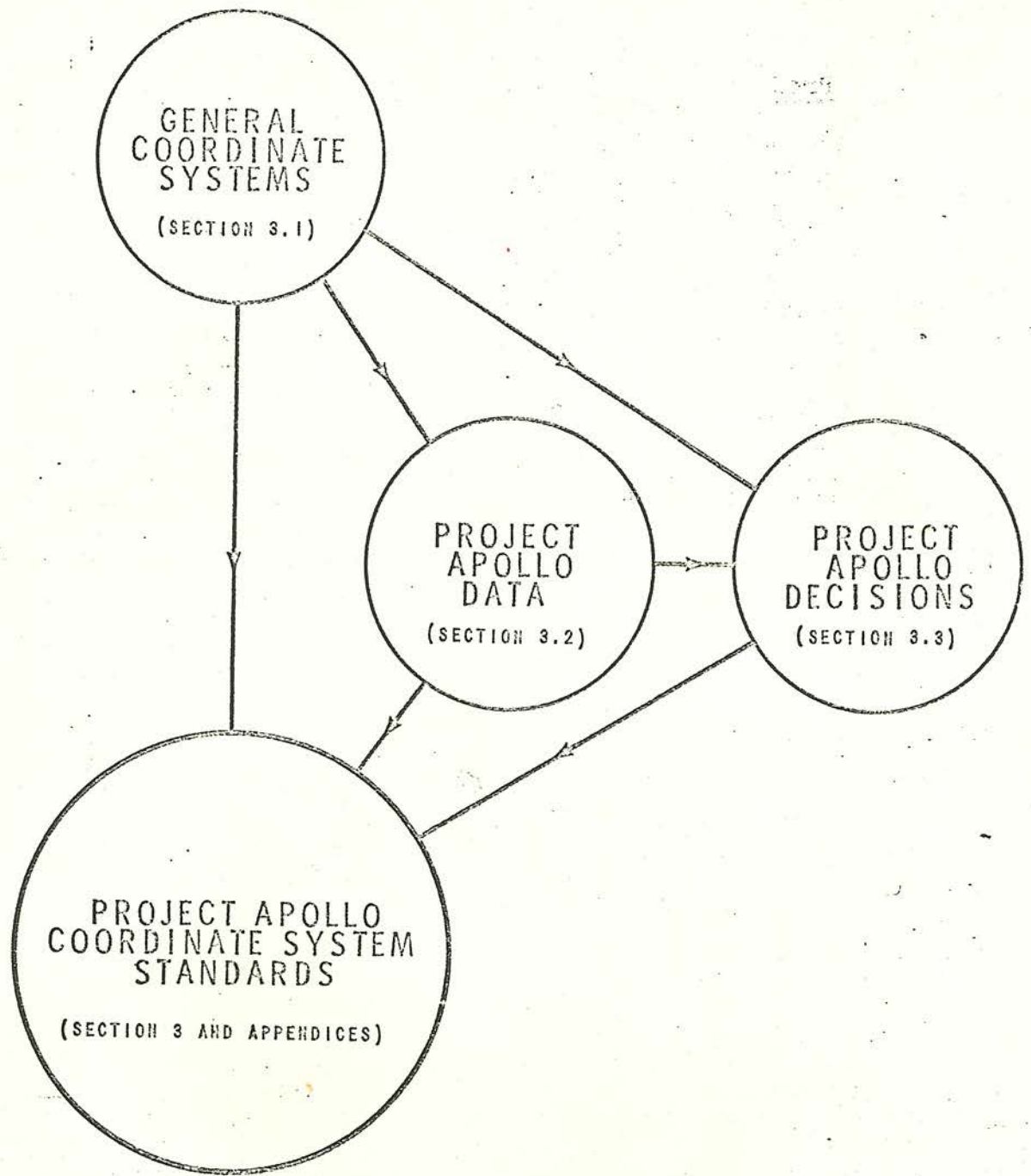### 2.1 General Coordinate Systems

Past practice provided a wealth of coordinate systems
from which appropriate selections were made for stan-
dardization in Project Apollo. Often the definitions
were quite entangled with the specific functional use;
separating them resulted in a group of general coordi-
nate systems which were defined in a basic and funda-
mental manner. A number of these general coordinate
systems were placed directly in the PACSS without elabor-
ation. The remaining systems in the general grouping
required further definition in order to be useful.

2.2 Project Apollo Data

Certain of the general coordinate systems were not
immediately applicable to Project Apollo, simply
because of the excessively general nature of their
definition. With the introduction of specific Apollo
physical data the ambiguity present in many of these
definitions was removed and they became acceptable as
Apollo Standard Coordinate Systems. However, a few
coordinate systems still required additional informa-
tion before they became applicable.

GENERAL
COORDINATE
SYSTEMS

(SECTION 3.1)

PROJECT
APOLLO
DATA

(SECTION 3.2)

PROJECT
APOLLO
DECISIONS

(SECTION 3.3)

PROJECT APOLLO
COORDINATE SYSTEM
STANDARDS

(SECTION 3 AND APPENDICES)

APPROACH DIAGRAM

- 3 -

2.3   Project Apollo Decisions

Adequate definition of the remaining coordinate systems was attained by incorporating information concerning specific Apollo project decisions. Generally these decisions consisted of ground rules and constraints relating to the use of the Standard Coordinate Systems. Furthermore, by recording Standard Relationships which must exist among certain coordinate systems during various phases of the mission, additional standards were created. Consequently, there is a meaningful distinction between a Standard Coordinate System and a Project Apollo Coordinate System Standard (PACSS); the latter is the general category and includes the former.

3.   DISCUSSION OF PROJECT APOLLO COORDINATE SYSTEM
      STANDARDS

The complete set of Project Apollo Coordinate
System Standards are contained in the Appendices.
The discussion in this section is keyed to the
Approach Diagram (page 3) and presents additional
information concerning these coordinate system
standards. The Appendices consist almost entirely
of figures, generally one standard per figure.
Figures A-1 through A-13 in Appendix A define
Project Apollo Standard Coordinate Systems.
Figures B-1 through B-3 in Appendix B define
Standard Relationships among two or more Standard
Coordinate Systems; in each of these cases the
relationship itself is an Apollo Standard. In
the following discussion frequent reference will
be made to these figures.

A tabulation of the general coordinate systems to
be applied to Project Apollo is presented in Table
I, page 6. These systems have been subdivided for
convenience according to whether they are rotating
or non-rotating with respect to space-direction
fixed axes and according to the body to which they
are referenced, i.e., Earth, Moon, or vehicle.
Table I contains only the standardized names of
the coordinate systems and is introduced here to
establish perspective.

3.1   General Coordinate Systems Applied Directly to
       the Standards

There are a number of the general coordinate
systems shown in Table I which can be applied
directly to Project Apollo without further infor-
mation or modification, specifically:

Geographic Polar   Figure A-1

Selenographic Polar   Figure A-2

Radar   Figure A-3
                                (a through d)

Geocentric Inertial   Figure A-4

TABLE I

TABULATION OF GENERAL COORDINATE SYSTEMS

THE CENTER OF THE COORDINATE SYSTEM IS REFERENCED TO THE:

THE AXES OF THE COORDINATE SYSTEM ARE:	VEHICLE	EARTH	MOON
ROTATING	o STRUCTURAL BODY AXES (DYNAMICAL BODY AXES) o MASS PROPERTIES	o GEOGRAPHIC POLAR o RADAR o EARTH-FIXED LAUNCH SITE o EARTH-CENTERED LAUNCH DERIVED	o SELENOGRAPHIC POLAR
NON-ROTATING	o PLATFORM-ACCELEROMETER	o GEOCENTRIC INERTIAL o IMPACT PREDICTION QUASI-INERTIAL o EARTH-MOON PLANE o ORBITAL ELEMENTS o NAVIGATION	o SELENOCENTRIC INERTIAL o EARTH-MOON PLANE o NAVIGATION

It is interesting to note that all of these
systems are either Earth or Moon Referenced.
The remaining systems listed in Table I require
additional project information in order to become
well-defined standards.

3.2   Project Apollo Data Applied to the Standards

The definitions of the Standard Coordinate Systems
introduced in this section are completed by the
application of specific Apollo data to the rotating
vehicle referenced coordinate systems of Table I
which are otherwise ambiguous.

The general standard for the Structural Body
Axes* system (Figure 1, page 8) only specifies
that the X axis lies along the vehicle longitudinal
axis, the origin is located with respect to a
reference point on the longitudinal axis and the
Z axis is defined by a vehicle benchmark.   Thus,
in order to obtain each specific Project Apollo
standard it was necessary to define the hardware-
related origin of the system and the appropriate
benchmark defining the positive Z axis for each
of the Apollo vehicles.   The Structural Body Axes
systems for the Apollo vehicles are:

A.   Launch Vehicles

    1.   Saturn I and IB (Figure A-8a).

        The origin is located on the longitudinal
    axis 100 inches below the gimbal reference
    plane.   Position I (alternatively, fin I)
    defines the positive Z direction.

---

*The Dynamical Body Axes system for any configuration
is obtained by a pure translation of the appropriate
Structural Body Axes system to the instantaneous center
of mass of that configuration (see Section 3.3.2).

ORIGIN REFERENCE POINT

Z AXIS BENCHMARK
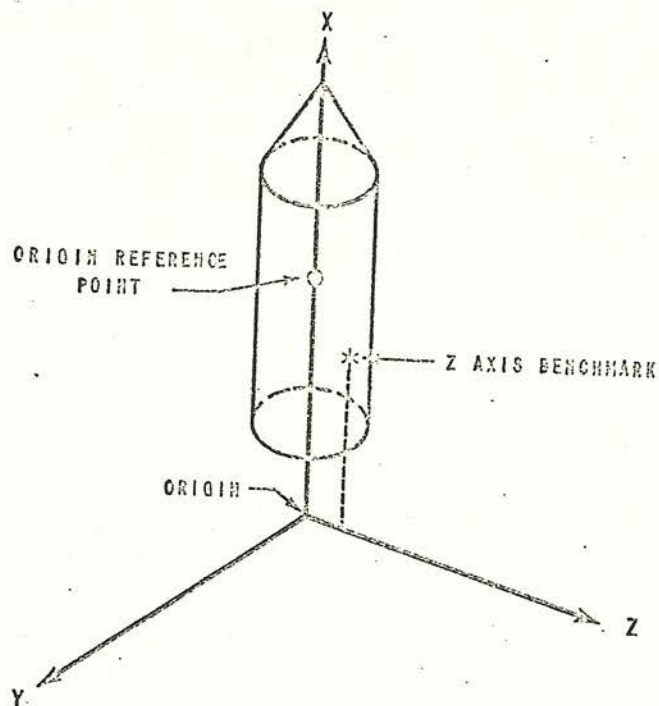
ORIGIN

TYPE: Rotating, vehicle referenced

ORIGIN: Located on the vehicle's longitudinal axis and defined with respect to a specified reference point, which is fixed relative to the vehicle structure.

ORIENTATION AND LABELING

The X axis lies along the longitudinal axis of the vehicle, positive in the nominal direction of positive thrust acceleration.

The Z axis is perpendicular to the X axis and lies in the plane defined by the X axis and a specified vehicle benchmark, positive toward the benchmark.

The Y axis completes a standard right-handed system.

The Dynamical Body Axes system is defined as a pure translation of the Structural Body Axes system to the instantaneous vehicle center of gravity.

Figure 1   STRUCTURAL BODY AXES (Dynamical Body Axes)

2. Saturn V (Figure A-8b).

   The origin is located on the longitudinal
   axis 100 inches below the gimbal reference
   plane. Position I defines the positive Z axis.

B. Command and Service Module (Figure A-8c)

   The origin is located on the longitudinal
   axis 1000 inches below the mold line of the
   CSM heat shield main structure ablator inter-
   face. The benchmark defining the positive Z
   axis is an alignment target (labeled +Z) at
   the top of the service module.

C. Lunar Excursion Module (Figure A-8d)

   The origin is located 200 inches below the LEM
   Ascent stage base. The positive Z axis is not
   defined by a physical benchmark; however, the
   center of the LEM exit hatch serves as a reference
   benchmark. Thus the positive Z axis is parallel
   to the center line of the exit hatch.

The Mass Properties system (Figure A-9), in which
the mass characteristics of the space vehicle and
its systems, subsystems and components are described,
is consistent in axes orientation and labeling with
the CSM Structural Body Axes. The origin of this
system is not specified uniquely; thus, for inter-
change of mass property data, it is essential that
the origin be explicitly stated.*

3.3 Project Apollo Decisions Applied to the Standards

This section is primarily concerned with the descrip-
tion and/or specification of Standard Relationships
which exist among various members of the Apollo
Standard Coordinate Systems. In the development of
these Standard Relationships, which arise from basic
project decisions, the four general coordinate systems
remaining in Table I are introduced and defined.

---

*The origin for CSM and LEM mass data is the same
as for the CSM Structural Body Axes. The origin
for the launch vehicle is the same as for the launch
vehicle Structural Body Axes.

3.3.1 Relationships Among Coordinate Systems Related to Apollo Navigation, Guidance and Control

Several interrelationships exist among the coordinate systems involved in the navigation, guidance and control functions; these interrelationships are basically the same for the Launch Vehicle, CSM, CM and LEM. The Dynamical Body Axes, Platform-Accelerometer and Navigation coordinate systems are common to all powered flight phases and these are discussed first. Several additional systems which apply only during the launch phase are treated later.

The Dynamical Body Axes system of a particular vehicle is always translatable with its Structural Body Axes system. Consistent use of the standard axes designations results in a "normally expected" orientation of the vehicle with respect to the flight path. For example, in the Launch Vehicle and CSM the axes commonly termed pitch*, roll and yaw are identical with the y, x and z directions, respectively. This is not so in the LEM because the pitch, roll and yaw designations (y, z, x, respectively) have been assigned in a manner which is consistent with astronaut orientation rather than one which is consistent with common vehicle practice.

The Platform-Accelerometer system is used for vehicle attitude reference and to define the orientation of the accelerometers. The orientation of the Platform-Accelerometer system is determined at the time of erection of the platform. Gimbal angles relate the position of the Dynamical Body Axes to this space-direction fixed system.

The Navigation system has its origin centered in a specified (usually the dominant) central body and is translatable with the Platform-Accelerometer system for computational convenience. Specific operational orientations for the Platform-Accelerometer and Navigation coordinate systems will vary throughout the Mission.

---

*Because of the inconsistent definitions of pitch, roll and yaw with respect to the x, y and z Body Axes systems, it is recommended that these terms not be depended upon to define directions of vehicle or platform axes.

The Dynamical Body Axes, Platform-Accelerometer and Navigation systems have interrelated roles during powered flight. The rules for the operational use of these systems are generally such as to keep them all as nearly in alignment as possible during any powered flight interval. A typical relative alignment of these three systems is shown for the spacecraft in Figure 2 (page 12), where the central body pictured is the Moon. The Platform-Accelerometer system is aligned with the X axis in the general direction of positive thrust (typically this may be either the initial or average thrust direction for the burn). The Y axis direction is defined by the vector cross product of the positive X axis into the vehicle position vector; the Z axis completes a standard right handed system.

The relative alignment of these three systems is basically the same for the launch vehicle as for the spacecraft. However, the Platform-Accelerometer Y axis becomes ill defined for the Earth launch since the thrust vector (X axis) and the position vector are nearly colinear. Therefore, at launch the Platform-Accelerometer axes are defined with the X axis along the local reference ellipsoid normal*, positive outward and the Z axis in the plane defined by the X axis and aiming azimuth, positive down range.

Similarly, when launching from the Moon the LEM Platform-Accelerometer system is aligned with the X axis along a reference vertical and the Z axis in the direction of the aiming azimuth.

For the launch phase, conditions are sufficiently invariant from mission to mission that specific standards can be defined. The following four Standard Coordinate Systems are associated with launch vehicle navigation, guidance and control.

Earth-Fixed Launch Site	Figure A-10
Earth-Centered Launch Derived	Figure A-11
Launch Vehicle Platform-Accelerometer	Figure A-12
Launch Vehicle Navigation	Figure A-13

---

*The reference ellipsoid is chosen to best fit the geoid or some portion of it; the Apollo standard is the 1960 Fischer ellipsoid.

Z

NAVIGATION

MOON

X

Z

Z

DYNAMICAL BODY AXES

PLATFORM - ACCELEROMETER

X

X
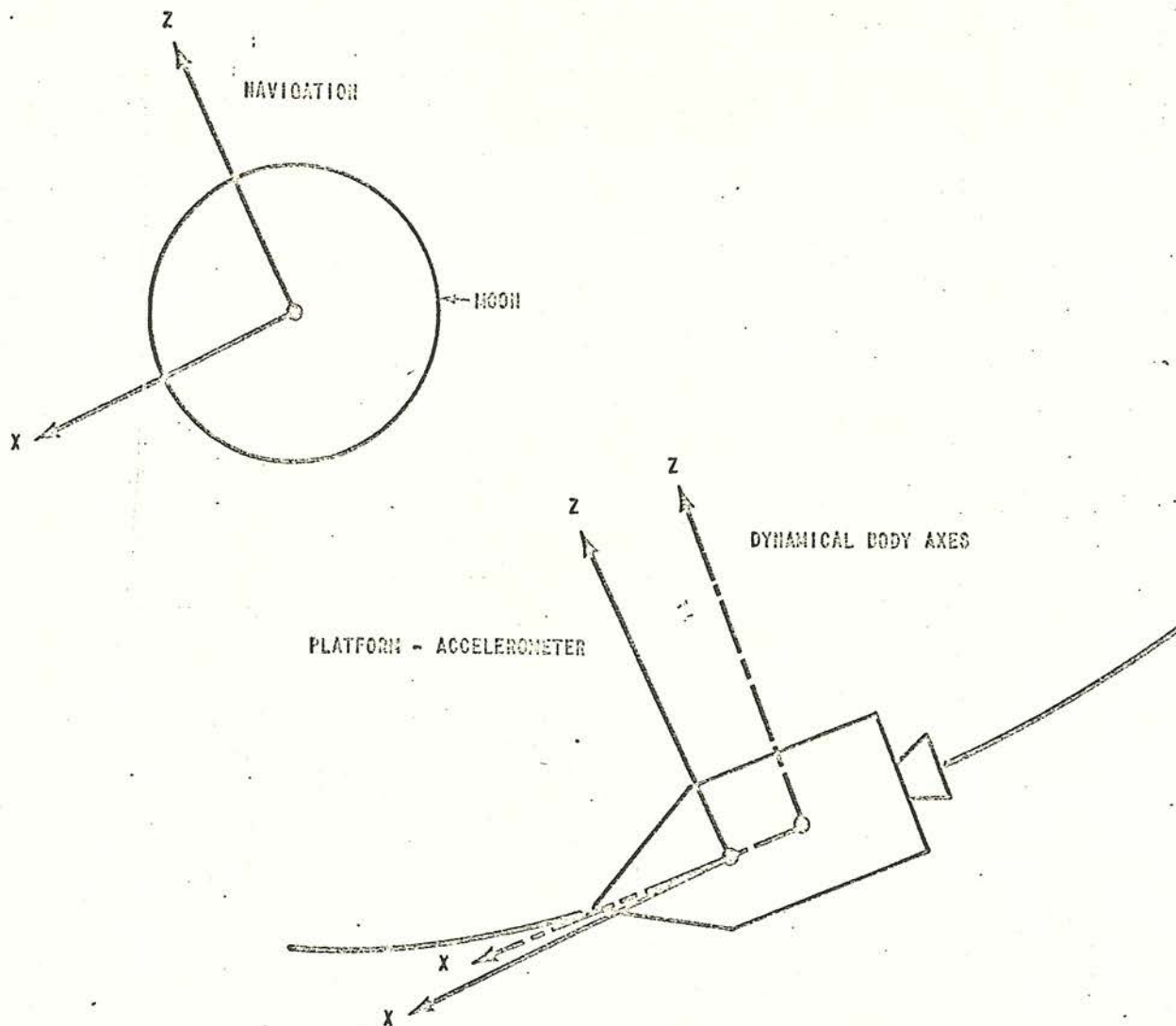
NOTE: COORDINATE SYSTEMS WHICH ARE
TRANSLATABLE HAVE BEEN DRAWN
WITH A SOLID LINE.

FIGURE 2 RELATIONSHIPS OF SPACECRAFT DYNAMICAL BODY AXES, PLATFORM-
ACCELEROMETER AND NAVIGATION COORDINATE SYSTEMS
(SIMPLIFIED PLANAR VIEW)

The Earth-Fixed Launch Site system is rotating
with the Earth and oriented in the direction of
launch. It is expressed in terms of the reference
ellipsoid and requires an exact specification of
both the launch site location and the aiming azimuth
for the trajectory. This system leads to the defini-
tion of the Launch Vehicle Platform-Accelerometer
system at guidance reference release time when the
gyros are uncaged and the stable platform becomes
space-direction fixed. The Earth-Centered Launch
Derived system is defined to be translatable at
all times with the Earth-Fixed Launch Site system.
The Launch Vehicle Navigation system is in turn
defined to be identical to the Earth-Centered Launch
Derived system at guidance reference release time.
Thus, two rotating systems, the Earth-Fixed Launch
Site and the Earth-Centered Launch Derived, give
rise to two non-rotating systems, the Launch Vehicle
Platform-Accelerometer and the Launch Vehicle Navi-
gation at guidance reference release time. A typical
relative alignment of the systems in this category is
shown in Figure 3 (page 14).

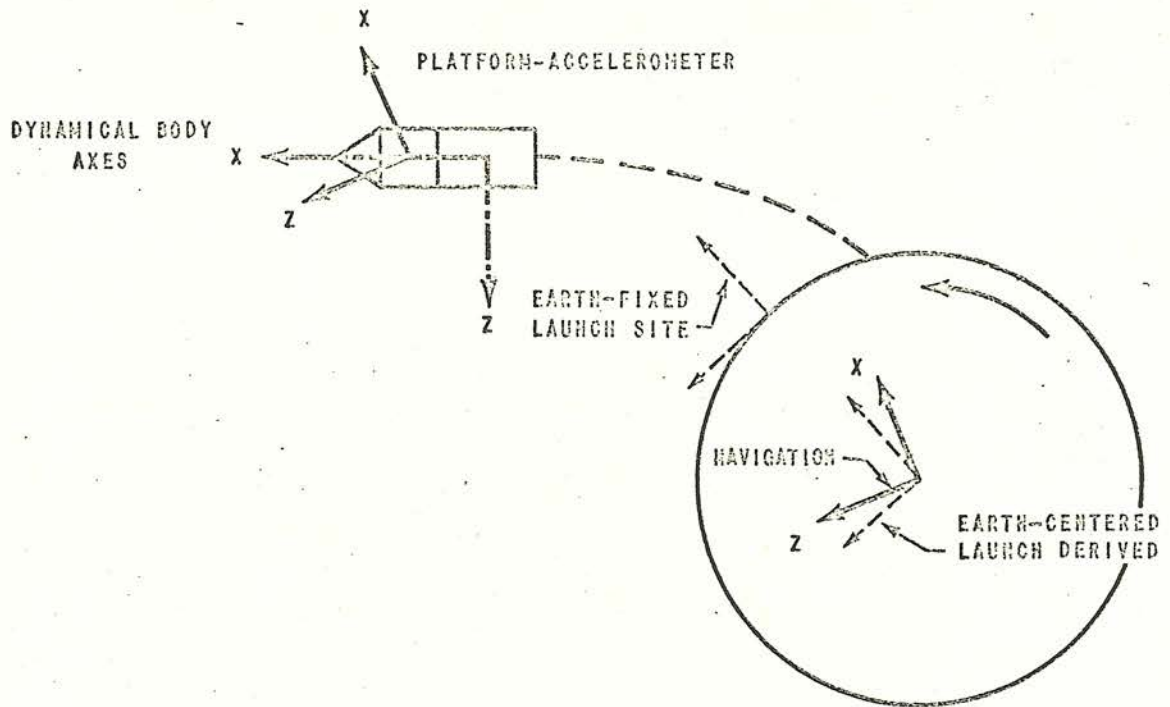3.3.2   Relationships Among the Structural Body Axes of the
            Apollo Vehicles

The Structural Body Axes systems as assigned in
section 3.2 exhibit a common property, which is
illustrated in Figure B-1*. Here the three Apollo
vehicles are shown side by side, each in its pre-
ferred powered flight attitude. Each vehicle, if
operating independently, would choose this orientation
to lift off and proceed down range in the positive Z
direction. This Standard Relationship results from
previous common practice, including pilot orientation
with respect to the flight path (see Reference 3).

There are two separate multi-vehicle configurations
in Project Apollo. The first occurrence is at Earth
launch, where the Standard Relationship between the
Structural Body Axes of the three vehicles is as shown
in Figure B-2*.

---

*The Structural Body Axes are the subjects of discussion;
however, to preserve clarity, the Dynamical Body Axes
are pictured in this figure. The Structural and Dynamical
Body Axes are translatable.

X

PLATFORM-ACCELEROMETER

DYNAMICAL BODY
AXES

X

Z

Y

Z

EARTH-FIXED
LAUNCH SITE

X

NAVIGATION

Z

EARTH-CENTERED
LAUNCH DERIVED

NOTE: THE AXES ORIENTATION OF THE
PLATFORM-ACCELEROMETER AND
NAVIGATION SYSTEMS ARE
DEFINED BY THE EARTH-FIXED
LAUNCH SITE AND EARTH-CENTERED
LAUNCH DERIVED SYSTEMS AT
GUIDANCE REFERENCE RELEASE
TIME.

COORDINATE SYSTEMS WHICH ARE
TRANSLATABLE ARE DRAWN WITH THE
SAME TYPE LINE (SOLID OR DASHED).

FIGURE 3   EARTH LAUNCH RELATED COORDINATE SYSTEMS
(PICTURED FOR A LAUNCH FROM THE EQUATOR INTO AN EQUATORIAL ORBIT)

The second is the normal docked configuration of the CSM/LEM spacecraft. The assignment of the Structural Body Axes for each individual vehicle is independent of its position in either of the stacked configurations. The implicit decision is that the standardization of coordinate systems for the individual vehicles is basically more important than having all coordinate systems translatable either at launch or in the docked configuration*. This is equivalent to treating the inactive vehicles as an inert payload.

A Structural Body Axes coordinate system can be defined for each multi-vehicle stack. The Standard Relationship defining this coordinate system requires that it be identical with the Structural Body Axes system of the primary or thrusting vehicle. Thus the space vehicle Structural Body Axes system shown in Figure B-3 is the same as that of the launch vehicle. For a multi-vehicle configuration, the origin of the Dynamical Body Axes is located at the center of mass of the configuration and not at the center of mass of the primary (thrusting) vehicle.

3.3.3   Relationships Among Coordinate Systems Under Backup Conditions

The pattern of the PACSS is such as to keep the separate vehicles autonomous and the coordinate systems consistent from vehicle to vehicle. It is thus necessary to carefully define the appropriate coordinate systems to be used when a multi-vehicle configuration exists. For the Structural Body Axes systems it has already been stated in section 3.3.2 that the coordinate system for any stack shall be that of the primary or thrusting vehicle, all other vehicles being considered inert. In cases where backup guidance must be ready to take over at any time, specific ground rules are necessary. The following simple rules provide consistent relations among the coordinate systems under backup guidance situations.

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*It should be noted that the individual vehicle coordinate systems could not have been assigned in any way that would allow them to be translatable for both stacked configurations.

o The backup Platform-Accelerometer coordinate
   system shall be translatable with that of
   the primary.

o The Dynamical Body Axes of the primary (thrusting)
   vehicle shall always be used, i.e. steering
   commands shall be transmitted in the coordinate
   system of the primary vehicle regardless of the
   source.

4.   SUMMARY

The Project Apollo Coordinate System Standards
consist of the following kinds of information:

o   definition of Standard Coordinate Systems
    consisting of

    a.   a descriptive name

    b.   position of the origin

    c.   orientation, positive direction and
         labeling of the axes

    d.   a time derivative notation

o   definition of Standard Relationships existing
    among Standard Coordinate Systems

All PACSS are contained in the Appendices; in general,
one standard per page. There are twelve Standard
Coordinate Systems (Figures A-1 through A-7 and A-10
and A-11) referenced to the Earth or Moon and generally
applicable in defining positions and/or velocities of
sites, vehicles and other bodies. Seven Standard
Coordinate Systems (Figures A-8 and A-9 and A-12 and
A-13) are related to the specific vehicles and vehicle
dynamics including navigation, guidance and control.
The standardization of relationships (Figures B-1
through B-3) is primarily among systems in this latter
group.

The most important underlying pattern in the standards
is the use of the same basic coordinate system defini-
tions for each vehicle including its navigation, guidance
and control. Multi-vehicle and/or backup situations are
controlled through the definition of Standard Relation-
ships among the coordinate systems associated with the
individual vehicles. Practical control of all such
situations is not possible by standardization alone
and thus normal practice should include identification
of the standard coordinate system being used and/or
configuration sketches.

5.   GLOSSARY

REFERENCE ELLIPSOID is an ellipsoid chosen to best
fit the geoid or some portion of it. For the
Earth, an oblate spheriod is normally used. The
Apollo standard is the 1960 Fischer ellipsoid.
More detailed information is available in Reference
2.

REFERENCED, as used in describing a coordinate system,
indicates the body with which the origin of the
system is associated. This terminology is used in
preference to the word "fixed" which connotes a
rigid attachment of the coordinate system to the
associated body. For example, the Geographic Polar
system defined with respect to the prime meridian
and the equatorial plane is rigidly "fixed" in the
Earth; whereas, the Geocentric Inertial system de-
fined with respect to the vernal equinox and the
equatorial plane is not "fixed" in the Earth but
is referenced to it.

ROTATING is used to indicate coordinate systems
whose axes exhibit angular motion with respect to
space fixed directions. There are no constraints
on the motion of the origin of such a system.

NON-ROTATING is used to indicate coordinate systems
whose axes exhibit no angular motion with respect
to space fixed directions. However, there are no
constraints on the motion of the origin of such a
system.

TRANSLATABLE coordinate systems have the property
that similarly labeled axes are parallel and have
the same positive directions.

6.

APPENDIX A

Project Apollo Standard Coordinate Systems

This Appendix contains the figures depicting the nineteen Standard Coordinate Systems. In the use of these standards, the dot convention for indicating time derivatives shall be adhered to when appropriate.
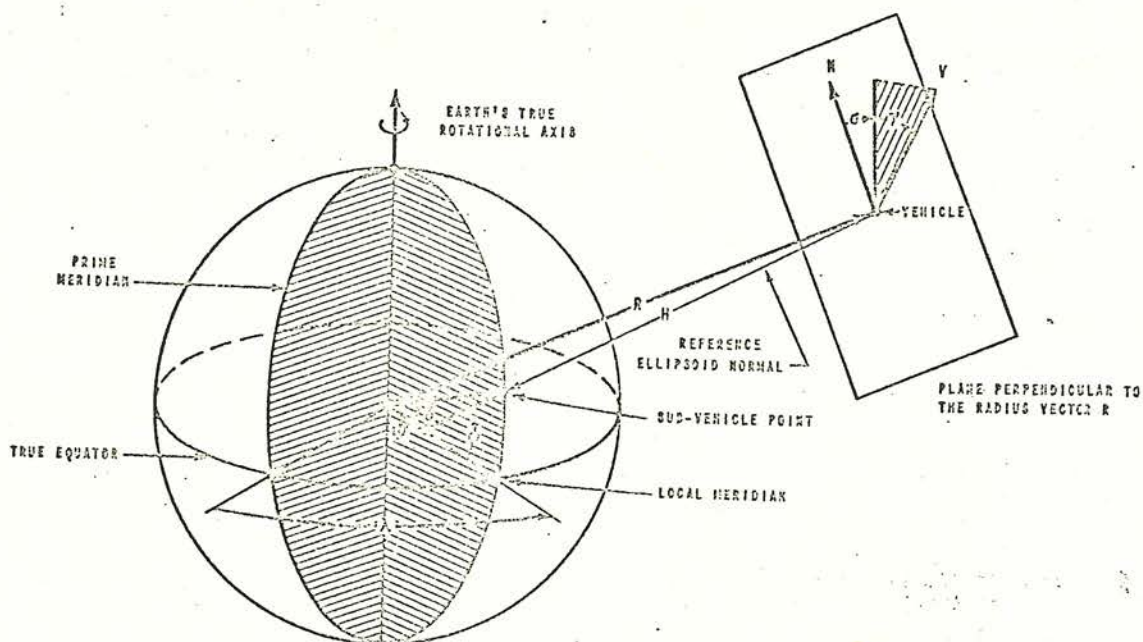
LIST OF PROJECT APOLLO STANDARD

COORDINATE SYSTEMS

TYPE: Rotating, Earth referenced

ORIGIN: The center of the Earth

ORIENTATION AND LABELING:

λ is the longitude measured positive eastward from the prime (Greenwich) meridian to the meridian containing the point of interest.

δ is the geocentric declination (angle between the geocentric radius vector and the true equatorial plane) measured positive north and negative south of the true equatorial plane.

The geodetic latitude ϕ is the angle defined by the intersection of the reference ellipsoid normal through the point of interest and the true equatorial plane, positive north and negative south of the true equatorial plane.

The geocentric latitude ψ is the angle between the true equatorial plane and the radius vector to the point of intersection of the reference ellipsoid and the reference ellipsoid normal passing through the point of interest, measured positive north and negative south of the true equatorial plane.

The altitude H is the perpendicular distance from the reference ellipsoid to the point of interest.

R is the magnitude of the geocentric radius vector to the point of interest.

V is the magnitude of the velocity (inertial or Earth-fixed) of the vehicle.

σ is the azimuth from north of the velocity vector projected on a plane normal to the geocentric radius vector to the vehicle.

γ is the flight path angle measured positive upward to the velocity vector from the plane normal to the geocentric radius vector.
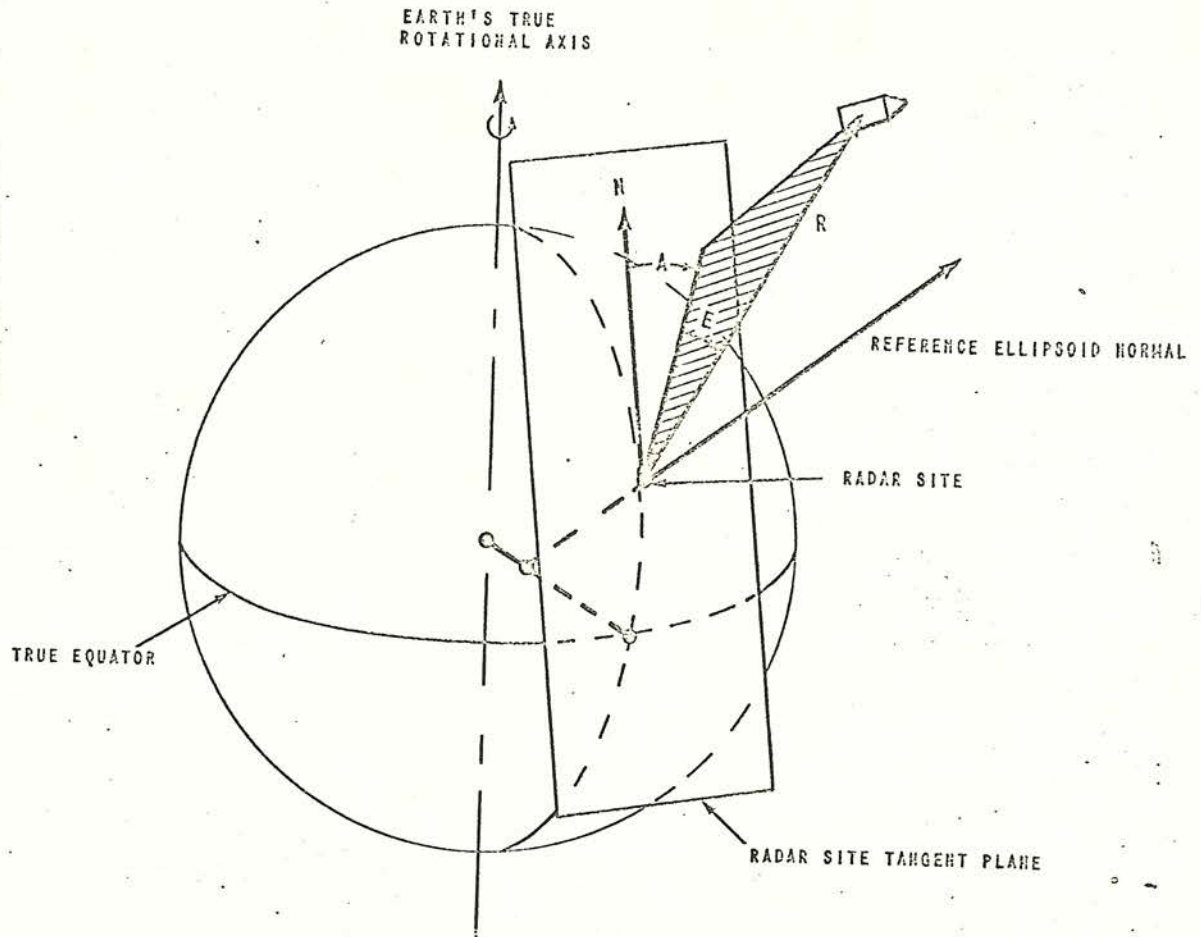
Subscripts are used to distinguish between the Earth-fixed and the inertial quantities. Specifically V_E, σ_E and γ_E define the Earth-fixed velocity and V_I, σ_I and γ_I define the inertial velocity.

FIGURE A-1

STANDARD COORDINATE SYSTEM 2
SELENOGRAPHIC POLAR

TYPE: Rotating, Moon referenced

ORIGIN: The center of the Moon

ORIENTATION AND LABELING:

The prime meridian passes through the mean center
of the apparent disk, which is the 0° latitude, 0°
longitude point.

The latitude ϕ is the angle defined by the inter-
section of the selenocentric radius vector to the
point of interest and the true lunar equatorial plane,
positive north (toward Mare Serenitatis) and negative
south of the true lunar equator.

The longitude λ is the angle measured along the
equatorial arc from the prime meridian to the
meridian containing the point of interest, positive
eastward (toward Mare Crisium).

R is the radial distance from the selenocenter to
the point of interest.

FIGURE A-2

STANDARD COORDINATE SYSTEM 3a

RADAR (AZ-EL)

EARTH'S TRUE
ROTATIONAL AXIS

REFERENCE ELLIPSOID NORMAL

RADAR SITE

TRUE EQUATOR

RADAR SITE TANGENT PLANE

TYPE: Rotating, Earth referenced

ORIGIN: The intersection of the radar axes

ORIENTATION AND LABELING:

The radar site tangent plane contains the site and
is perpendicular to the reference ellipsoid normal
which passes through the radar site.

R is the slant range to the vehicle.

A is the azimuth angle measured clockwise from
true north to the projection of the slant range
vector onto the radar site tangent plane.

E is the elevation angle measured positive above
the radar site tangent plane to the slant range
vector.

FIGURE A-3a

STANDARD COORDINATE SYSTEM 3b

RADAR (HA-DEC)
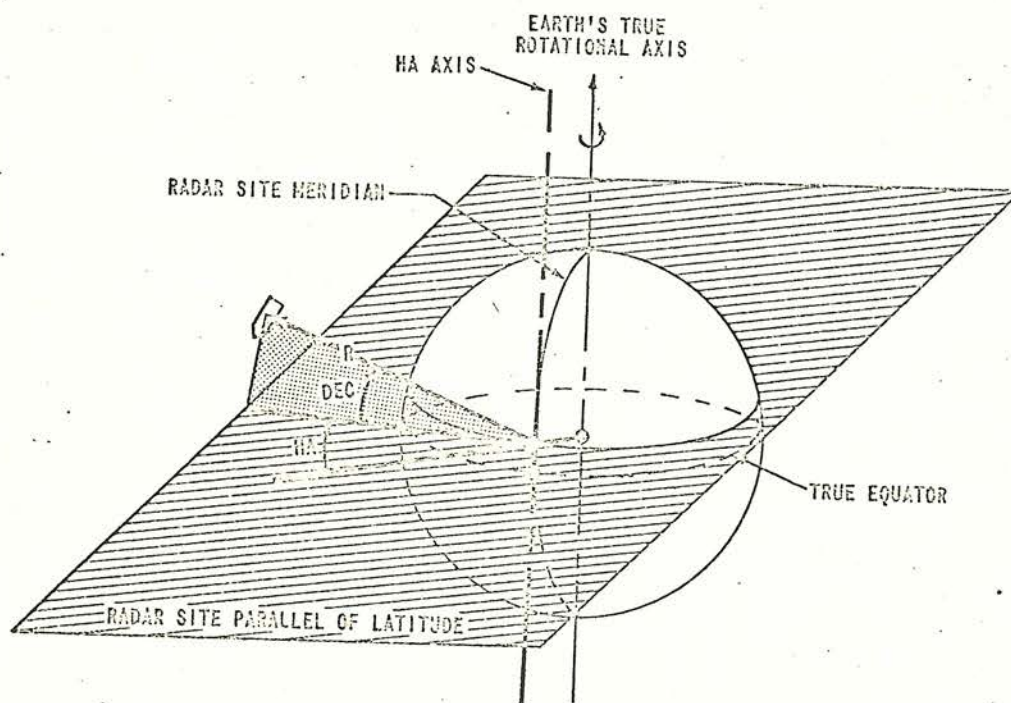
TYPE: Rotating, Earth referenced

ORIGIN: The point of intersection of the hour angle
           axis with the plane of the declination gear

ORIENTATION AND LABELING:

R is the slant range* to the vehicle.

The HA axis is parallel to the Earth's true
rotational axis. The declination axis is
parallel to the true equator and perpendicular
to the HA axis.

The hour angle (HA) is measured positive westward
in the plane of the local radar site parallel of
latitude, from the radar site meridian plane to
the plane perpendicular to the equator and contain-
ing the vehicle and the radar site.

The declination (DEC) is the angle measured from
the radar site parallel of latitude to the vehicle,
positive north and negative south of this plane.

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* Range rate ($\dot{R}$) data is also generally available
in this system.

FIGURE A-3b

STANDARD COORDINATE SYSTEM 3c

RADAR (X-Y 30 ft.)
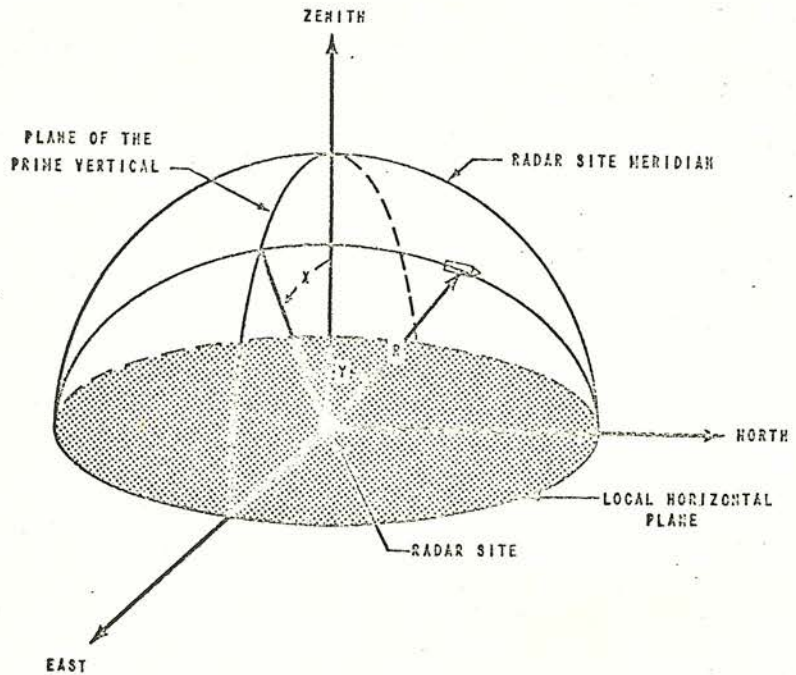
TYPE: Rotating, Earth referenced

ORIGIN: At the intersection of the X axis and
the plane of the Y axis gear

ORIENTATION AND LABELING:

R is the slant range*from the radar site
to the vehicle.

The X axis lies along the intersection of the
horizontal plane and the meridian plane at the
radar site. The Y axis is perpendicular to the
X axis.

X is the angle measured in the plane of the radar
site prime vertical from the zenith to the pro-
jection of the slant range vector, onto this plane,
positive eastward.

Y is the angle between the slant range vector and
its projection onto the plane of the radar site
prime vertical, positive when the slant range
vector is north of the plane and negative when it
is south of it.

(When the radar antenna is directed toward the
zenith, the X and Y angles are zero and the Y axis
is perpendicular to the radar site meridian plane.)

---

*Range rate ($\dot{R}$) data is also generally available in
this system.

FIGURE A-3c
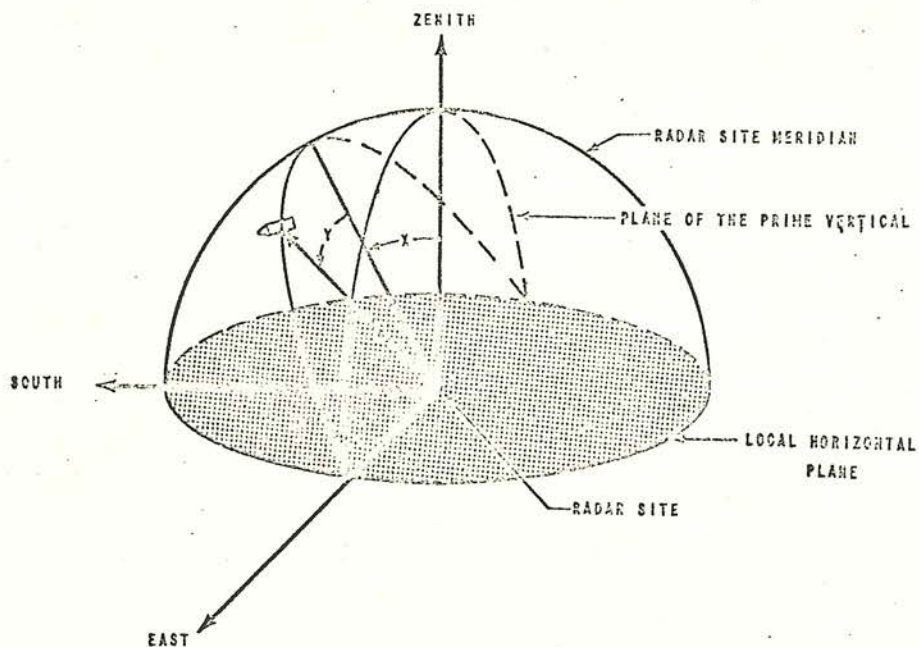
RADAR (X-Y 85 ft.)

FIGURE A-3d

TYPE: Rotating, Earth referenced

ORIGIN: At the intersection of the X axis and the plane of the Y axis gear

ORIENTATION AND LABELING:

R is the slant range* from the radar site to the vehicle.

The X axis lies along the intersection of the horizontal plane and the plane of the prime vertical at the radar site. The Y axis is perpendicular to the X axis.

X is the angle measure in the meridian plane of the radar site from the zenith to the projection of the slant range vector onto this plane, positive southward.

Y is the angle between the slant range vector and its projection onto the meridian plane of the radar site, positive when the slant range vector is east of the meridian plane and negative when it is west of it.

(When the radar antenna is directed toward the zenith, the X and Y angles are zero and the Y axis is perpendicular to the radar site prime vertical plane.)

---

* Range rate ($\dot{R}$) data is also generally available in this system.

STANDARD COORDINATE SYSTEM 4
GEOCENTRIC INERTIAL
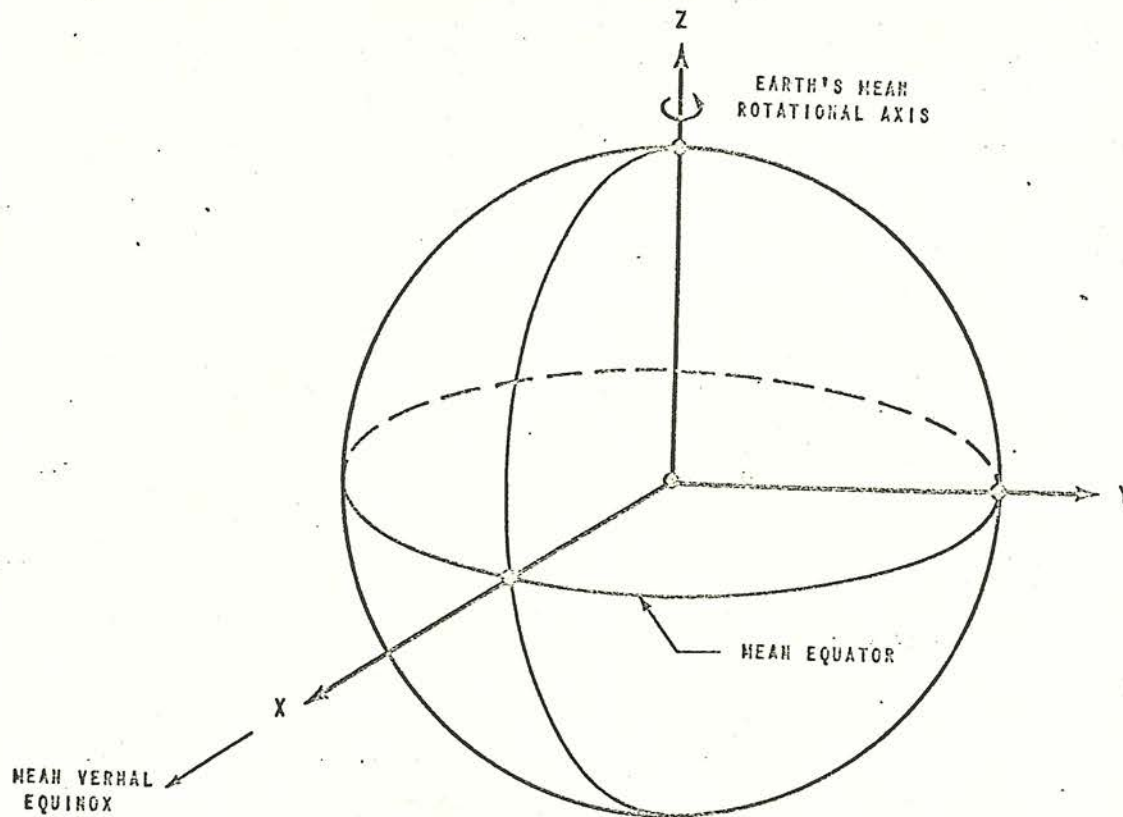
TYPE: Non-rotating, Earth referenced

ORIGIN: The center of the Earth

ORIENTATION AND LABELING:

The Z axis is directed along the Earth's mean rotational axis, positive north.

The X axis is directed toward the mean vernal equinox.

The Y axis completes a standard right-handed system.

The epoch will generally be the nearest beginning of a Besselian year. However, special applications may involve other epochs. Consequently, in any transmission of related data, the reference epoch used should be clearly stated.

This system is translatable to a Selenocentric Inertial system.

FIGURE A-4

STANDARD COORDINATE SYSTEM 5
IMPACT PREDICTION QUASI-INERTIAL
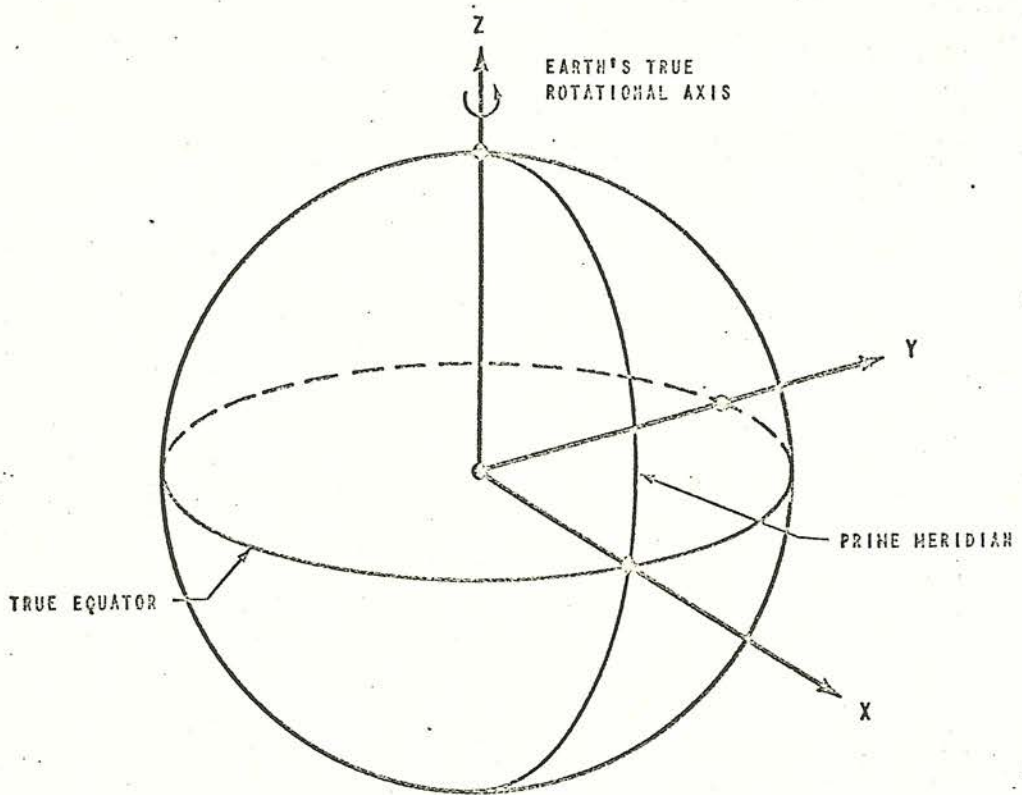
TYPE: Non-rotating, Earth referenced

ORIGIN: The center of the Earth

ORIENTATION AND LABELING:

This system is redefined at the beginning of each
computational cycle. It is an inertial system*
for the duration of each computational cycle.

The Z axis is along the Earth's true rotational
axis, positive north.

The positive X axis intersects the prime (Greenwich)
meridian at the beginning of each computational cycle.

The Y axis completes a standard right-handed system.

(The X-Y plane is the Earth's true equatorial plane.)

---

*Velocities expressed in this system are inertial
velocities.

FIGURE A-5

STANDARD COORDINATE SYSTEM 6
EARTH-MOON PLANE
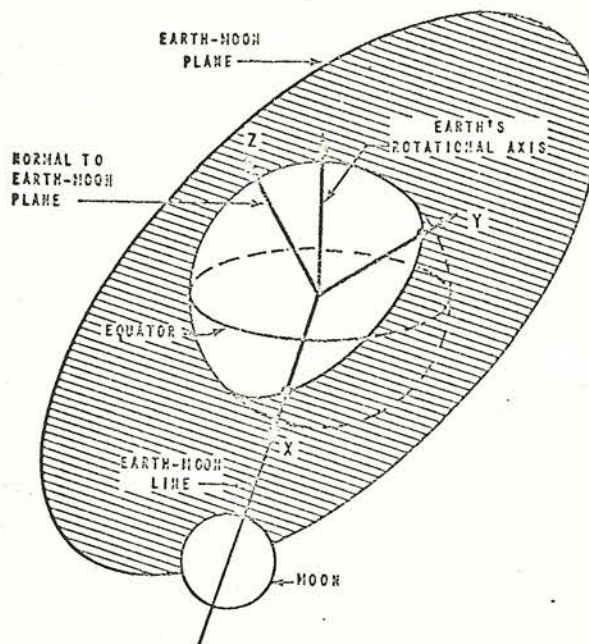
TYPE: Non-rotating

ORIGIN: The center of the specified central body
(Earth or Moon: The Earth-centered system
is shown in this Figure.)

ORIENTATION AND LABELING:

This system is redefined at the beginning of each
computational cycle. It is an inertial system* for
the duration of each computational cycle.

The X axis lies along the Earth-Moon line at the
beginning of each computational cycle, positive
away from the Earth toward the Moon.

The Z axis is normal to the Earth-Moon plane, and
parallel to the Moon's angular momentum vector,
positive in a northerly direction.

The Y axis completes a standard right-handed system.

(The X-Y plane is normal to the Moon's angular
momentum vector.)

This system is translatable to a selenocentric
Earth-Moon Plane system. In this case the positive
X axis lies along the extended Earth-Moon line and
is directed away from the Earth.

---

* Velocities expressed in this system are inertial
velocities.

FIGURE A-6

STANDARD COORDINATE SYSTEM 7
ORBITAL ELEMENTS
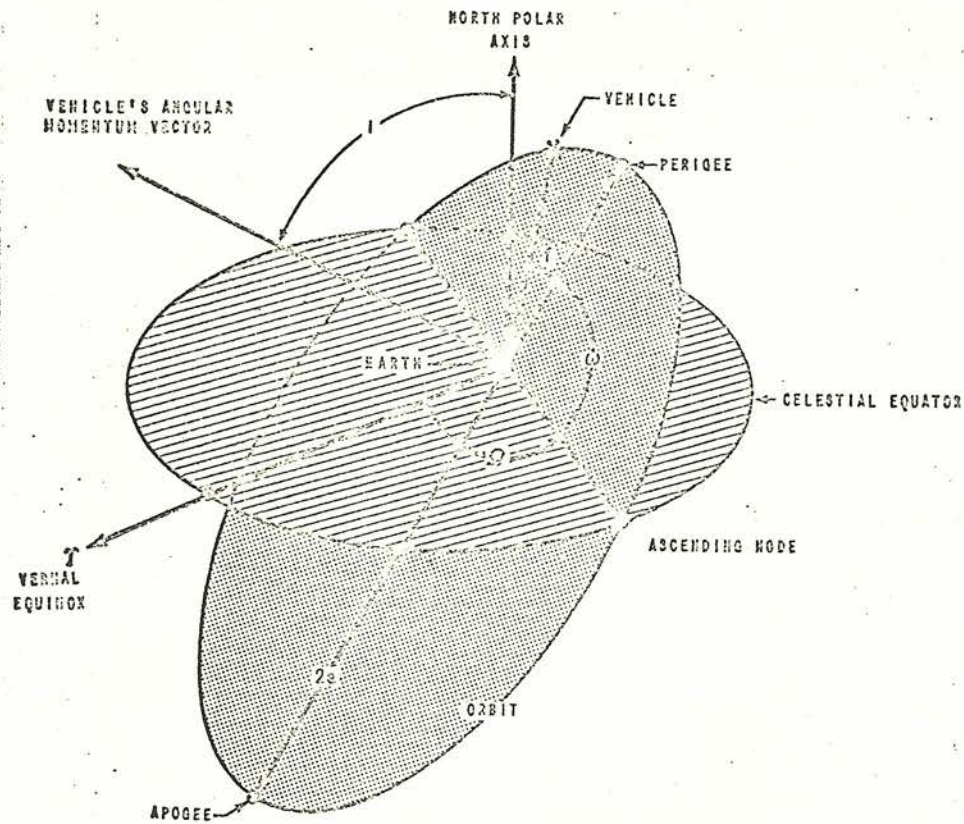
TYPE: Non-rotating, Earth referenced

ORIGIN: The center of the Earth

ORIENTATION AND LABELING:

a is the semi-major axis of the orbit.

e is the eccentricity of the orbit.

f, the true anomaly, is the geocentric angular displacement of the vehicle measured in the orbit plane from perigee, positive in the direction of travel in the orbit.

Ω, the right ascension of the ascending node, is the angle measured eastward from the vernal equinox along the equator to that intersection with the orbit where the vehicle passes from south to north.

ω, the argument of perigee, is the angle measured in the orbit plane between the ascending node and perigee, positive in the direction of travel in the orbit.

i, the inclination of the orbital plane, is the angle between the north polar axis and the vehicle angular momentum vector.

FIGURE A-7

STANDARD COORDINATE SYSTEM 8a
SATURN I AND IB LAUNCH VEHICLE STRUCTURAL BODY AXES
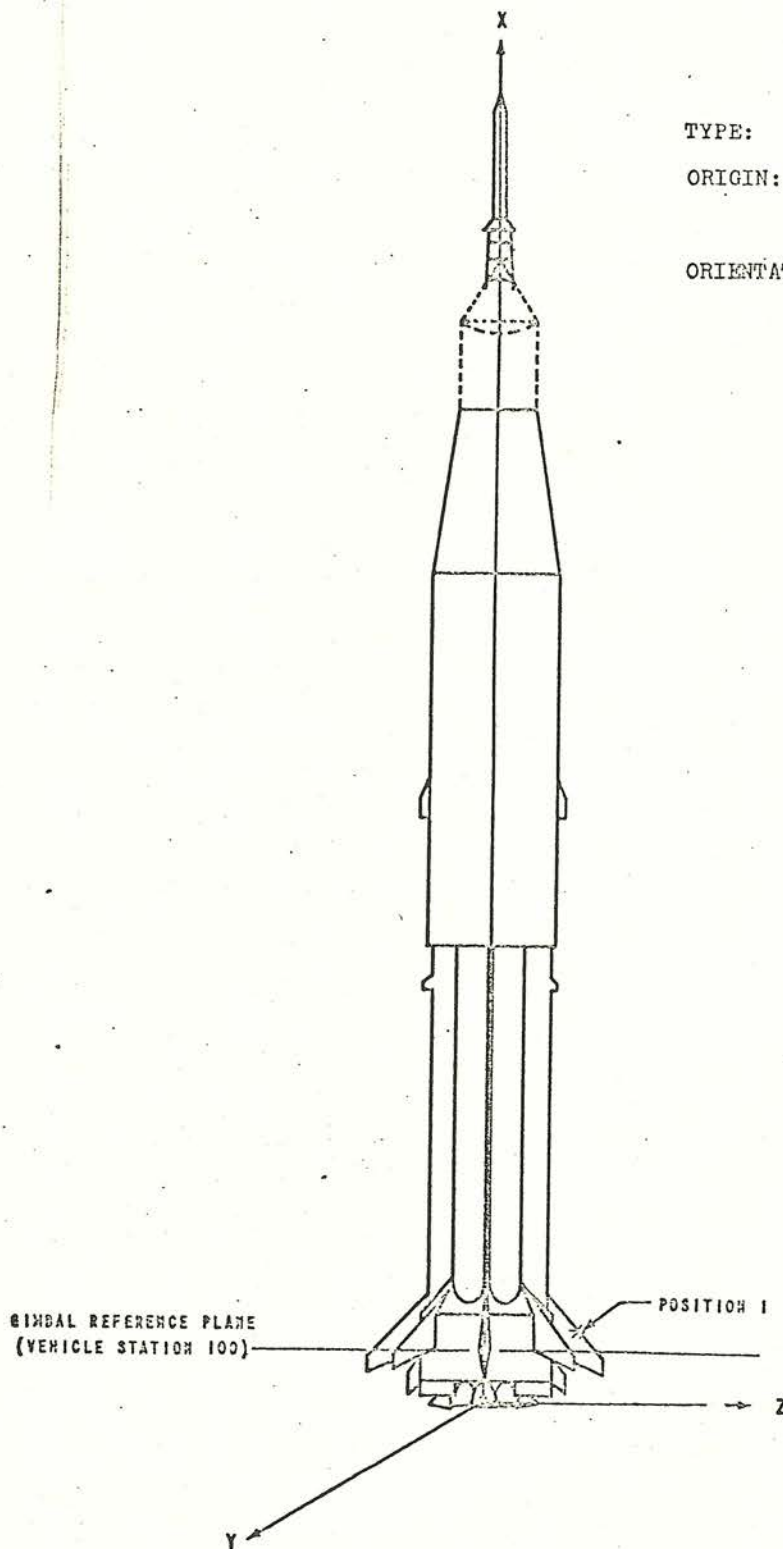
TYPE: Rotating, vehicle referenced

ORIGIN: On the longitudinal axis, 100 inches below the gimbal reference plane
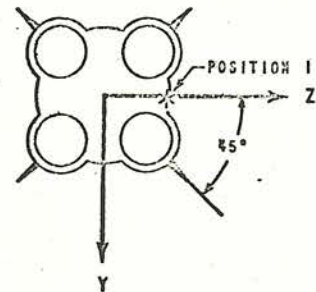
ORIENTATION AND LABELING:

The X axis lies along the longitudinal axis of the vehicle, positive in the nominal direction of positive thrust acceleration.

Position I (alternatively fin I) defines the positive Z direction.

The Y axis completes a standard right-handed system.

The Dynamical Body Axes system, which has its origin at the vehicle's instantaneous center of mass, is translatable with the Structural Body Axes system.

Launch Complexes 34 and 37 will be used for Saturn I and IB launchings. The positive Z axis of the erected vehicle will be directed approximately 100° 12' east of north for Launch Complex 34, and approximately 90° 12' east of north for Launch Complex 37.
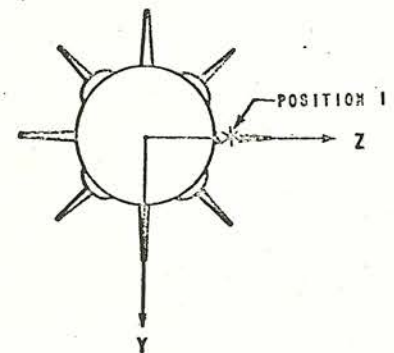
FIGURE A-8a
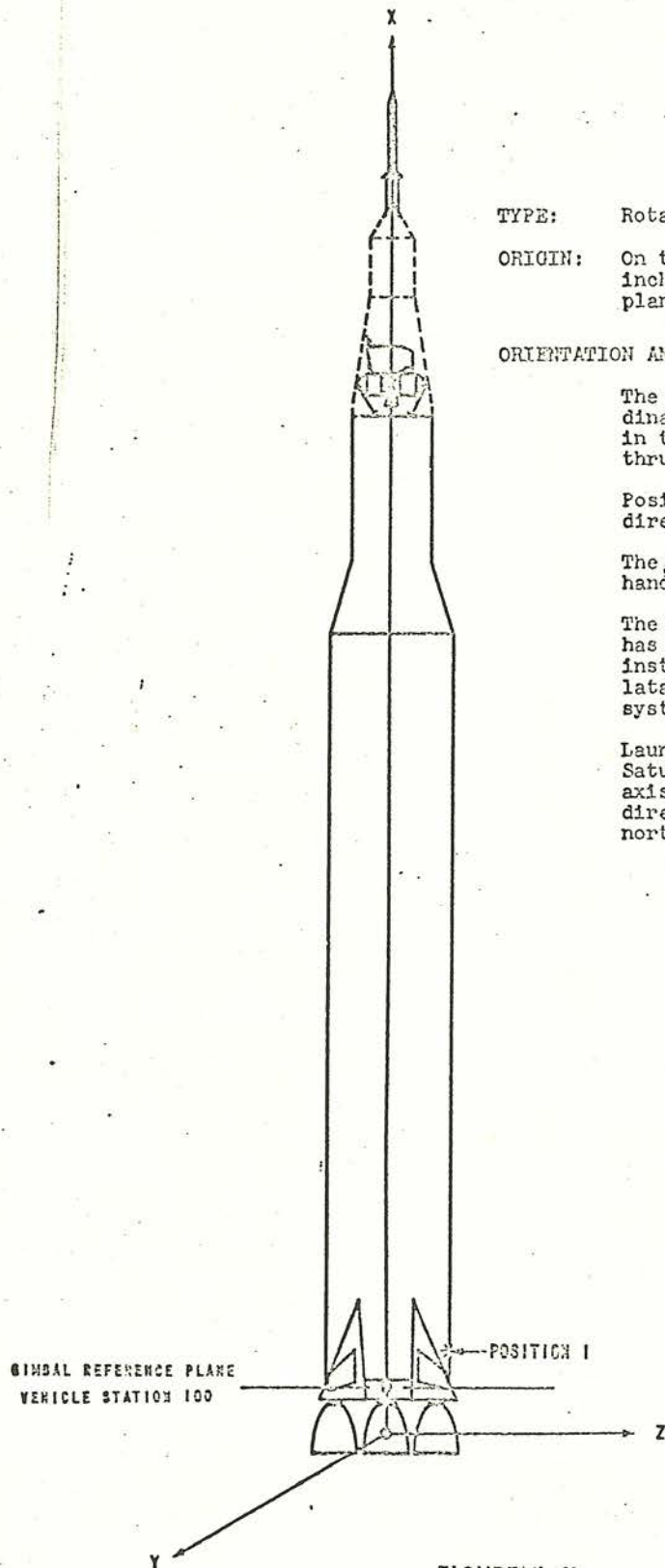
TYPE: Rotating, vehicle referenced

ORIGIN: On the longitudinal axis, 100 inches below the gimbal reference plane

ORIENTATION AND LABELING:

The X axis lies along the longitudinal axis of the vehicle, positive in the nominal direction of positive thrust acceleration.
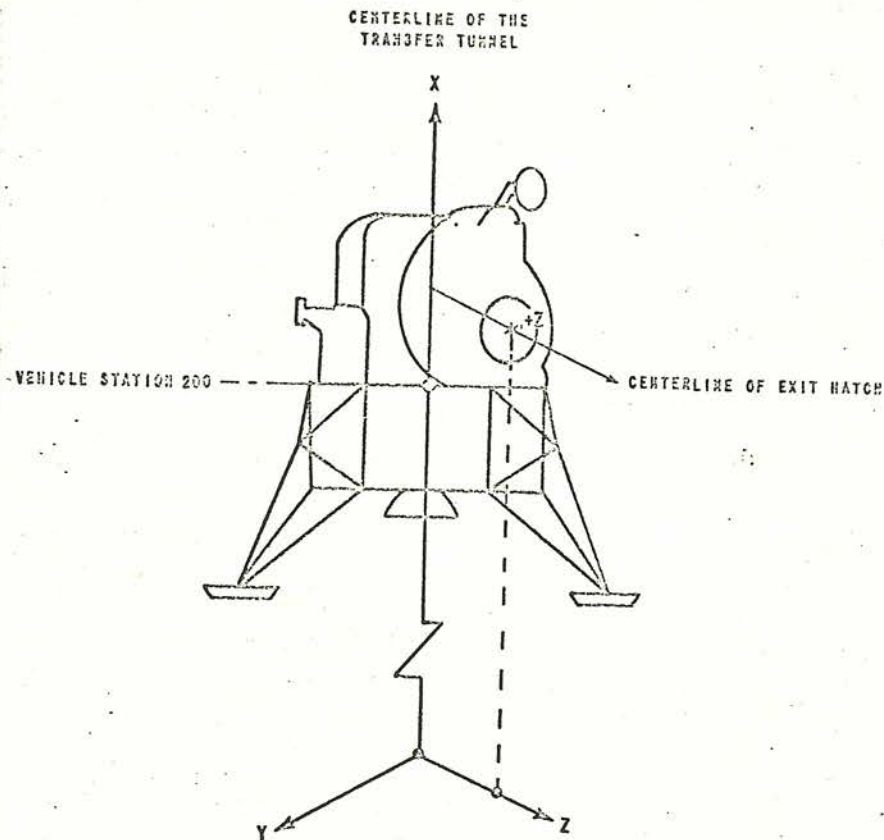
Position I defines the positive Z direction.

The Y axis completes a standard right-handed system.

The Dynamical Body Axes system, which has its origin at the vehicle's instantaneous center of mass, is translatable with the Structural Body Axes system.

Launch Complex 39 will be used for Saturn V launchings. The positive Z axis of the erected vehicle will be directed approximately 90° 12' east of north for this launch complex.

GIMBAL REFERENCE PLANE
VEHICLE STATION 100

POSITION I

TOP VIEW

FIGURE A-8b

STANDARD COORDINATE SYSTEM 8c
CSM STRUCTURAL BODY AXES
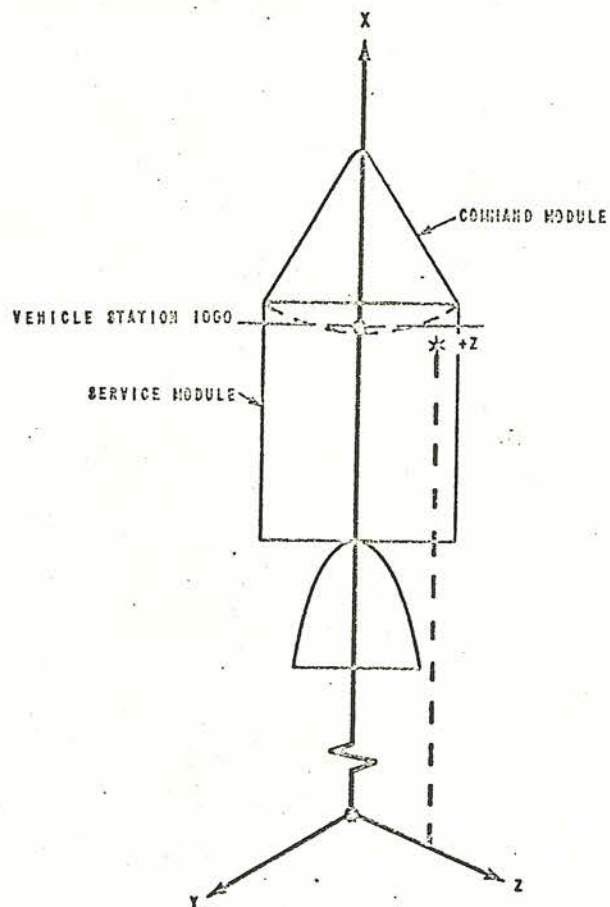
TYPE: Rotating, vehicle referenced

ORIGIN: On the longitudinal axis, 1,000 inches below
the mold line of the heat shield main structure
ablator interface.

ORIENTATION AND LABELING:

> The X axis lies along the longitudinal axis
> of the vehicle, positive in the nominal
> direction of positive thrust acceleration.

> The benchmark defining the positive Z axis is
> an alignment target (labeled +Z) at the top
> of the service module.

> The Y axis completes a standard right-handed
> system.

> The dynamical Body Axes system, which has its
> origin at the vehicle's instantaneous center of
> mass, is translatable with the Structural Body
> Axes system.

FIGURE A-8c

STANDARD COORDINATE SYSTEM 8d
LEM STRUCTURAL BODY AXES

CENTERLINE OF THE
TRANSFER TUNNEL

X

+Z

VEHICLE STATION 200

CENTERLINE OF EXIT HATCH

Y

Z

TYPE: Rotating, vehicle referenced

ORIGIN: Located 200 inches below the LEM Ascent
stage base

ORIENTATION AND LABELING:

The X axis lies along the longitudinal axis
(centerline of the transfer tunnel) of the
LEM, positive in its nominal direction of
positive thrust acceleration.

The positive Z axis is not defined by a
physical benchmark; however, the center of
the LEM exit hatch serves as a reference
benchmark. Thus, the positive Z axis is
parallel to the centerline of the exit hatch.

The Y axis completes a standard right-handed
system.

The Dynamical Body Axes system, which has its
origin at the vehicle's instantaneous center
of mass, is translatable with the Structural
Body Axes system.

FIGURE A-8d
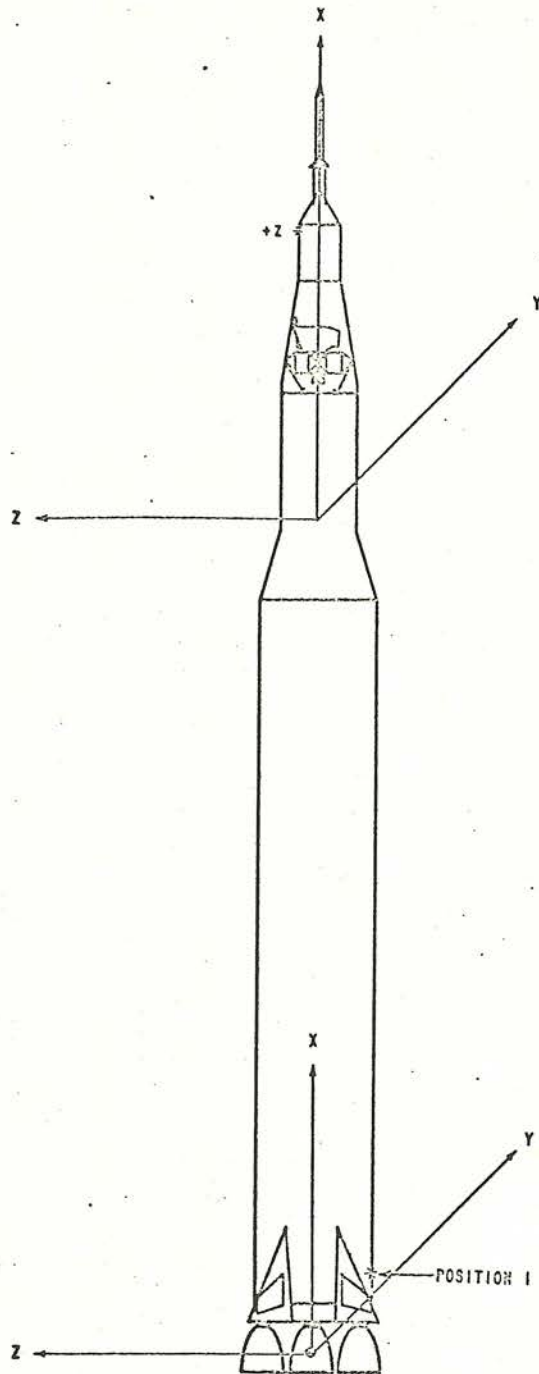
TYPE: Rotating, vehicle referenced

ORIGIN: Two origin are employed with
this system: one coincides
with the origin of the Launch
Vehicle Structural Body Axes
system and the other coincides
with the origin of the CSM
Structural Body Axes system.
The former is generally used
when transmitting launch
vehicle mass properties data
and the latter when trans-
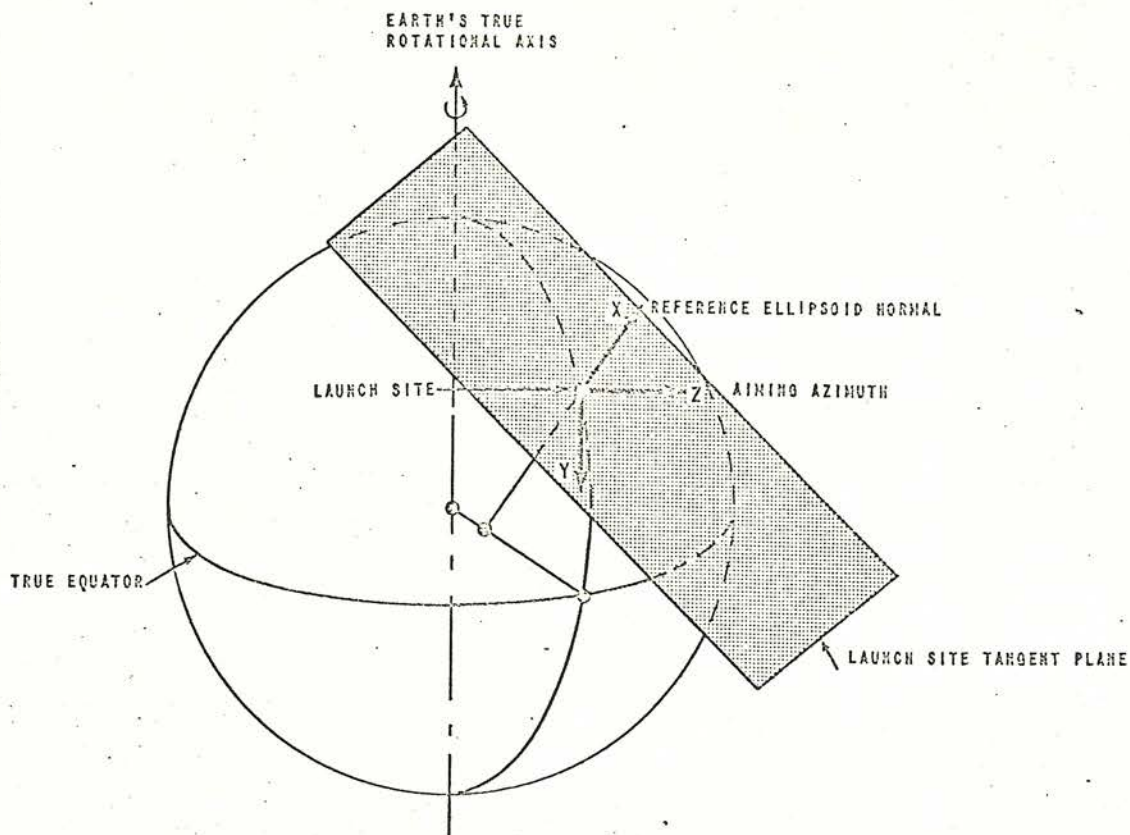mitting spacecraft mass
properties data.

ORIENTATION AND LABELING

In all cases the orientation
and labeling of the axes is
identical with that of the CSM
Structural Body Axes system
(Standard Coordinate System 8c).

FIGURE A-9

STANDARD COORDINATE SYSTEM 10
EARTH-FIXED LAUNCH SITE

TYPE: Rotating, Earth referenced

ORIGIN: At the intersection of the reference ellipsoid and the normal to it which passes through the launch site.

ORIENTATION AND LABELING:

The launch site tangent plane contains the site and is perpendicular to the reference ellipsoid normal which passes through the launch site.

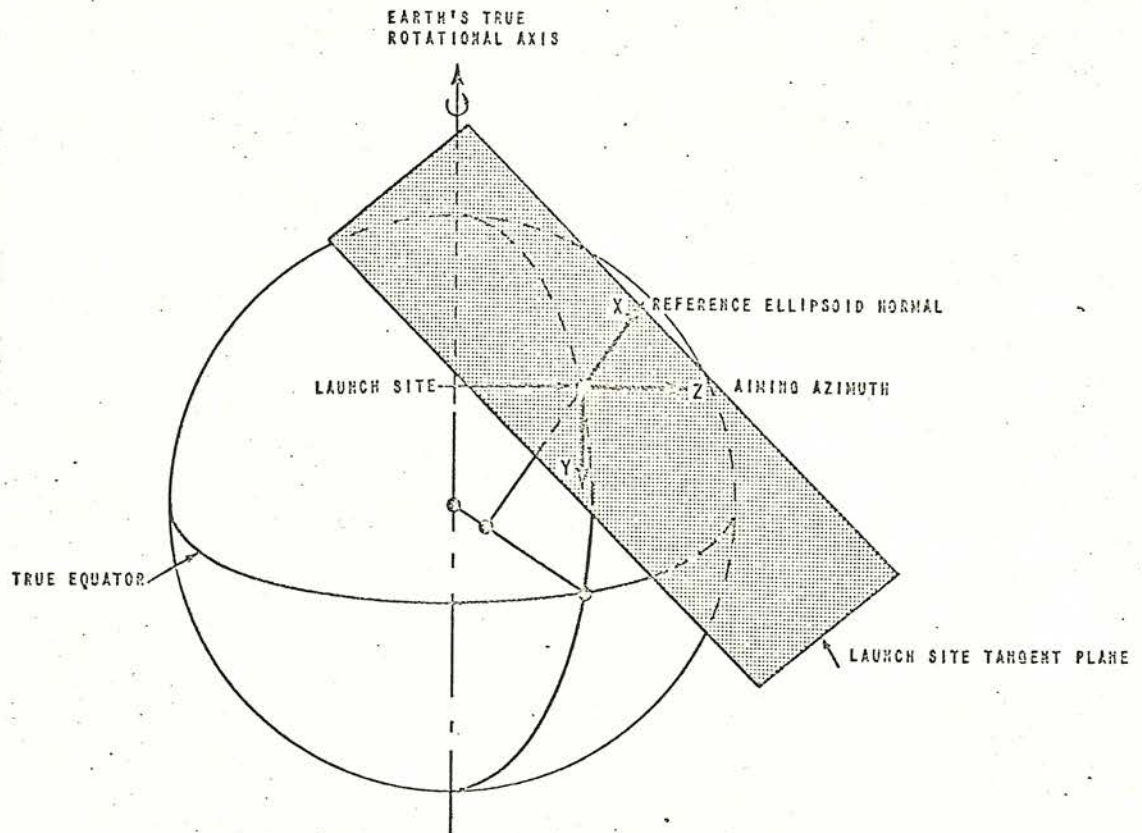The X axis coincides with the reference ellipsoid normal passing through the site, positive upward.

The Z axis is parallel to the Earth-fixed aiming azimuth, defined at guidance reference release time, and is positive downrange.

The Y axis completes a standard right-handed system.

(The Y-Z plane is the launch site tangent plane.)

FIGURE A-10

STANDARD COORDINATE SYSTEM 10
EARTH-FIXED LAUNCH SITE

EARTH'S TRUE
ROTATIONAL AXIS

X REFERENCE ELLIPSOID NORMAL

LAUNCH SITE

Z AIMING AZIMUTH

Y

TRUE EQUATOR

LAUNCH SITE TANGENT PLANE

TYPE: Rotating, Earth referenced

ORIGIN: At the intersection of the reference ellipsoid
           and the normal to it which passes through the
           launch site.

ORIENTATION AND LABELING:

    The launch site tangent plane contains the site
    and is perpendicular to the reference ellipsoid
    normal which passes through the launch site.

    The X axis coincides with the reference ellipsoid
    normal passing through the site, positive upward.

    The Z axis is parallel to the Earth-fixed aiming
    azimuth, defined at guidance reference release
    time, and is positive downrange.

    The Y axis completes a standard right-handed system.

    (The Y-Z plane is the launch site tangent plane.)

FIGURE A-10

STANDARD COORDINATE SYSTEM 11
EARTH-CENTERED LAUNCH DERIVED
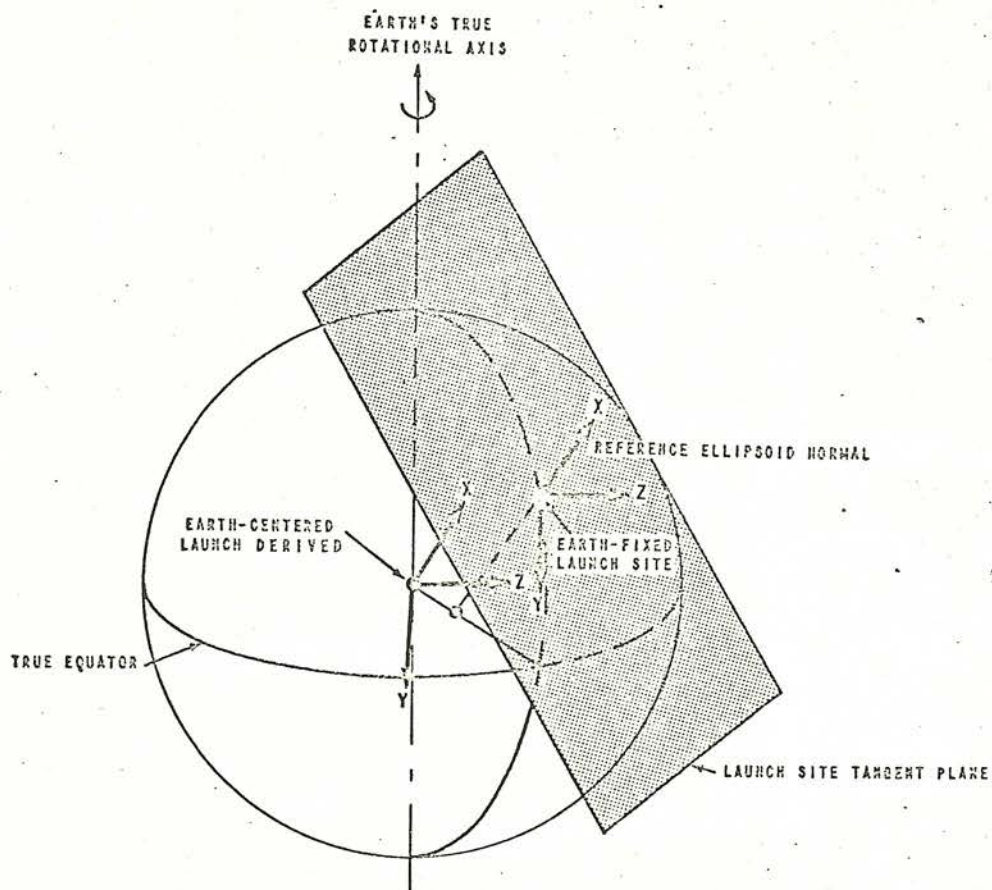
FIGURE A-11

TYPE: Rotating, Earth referenced

ORIGIN: The center of the Earth

ORIENTATION AND LABELING:

The launch site tangent plane contains the site and is perpendicular to the reference ellipsoid normal which passes through the launch site.

The X axis is parallel to the reference ellipsoid normal passing through the launch site and is positive toward the launch site.

The Z axis is parallel to, and positive in the same direction as, the Earth-fixed aiming azimuth.

The Y axis completes a standard right-handed system.

(The Y-Z plane is parallel to the launch site tangent plane).

This system is translatable with the Earth-Fixed Launch Site system.

STANDARD COORDINATE SYSTEM 12
LAUNCH VEHICLE PLATFORM-ACCELEROMETER
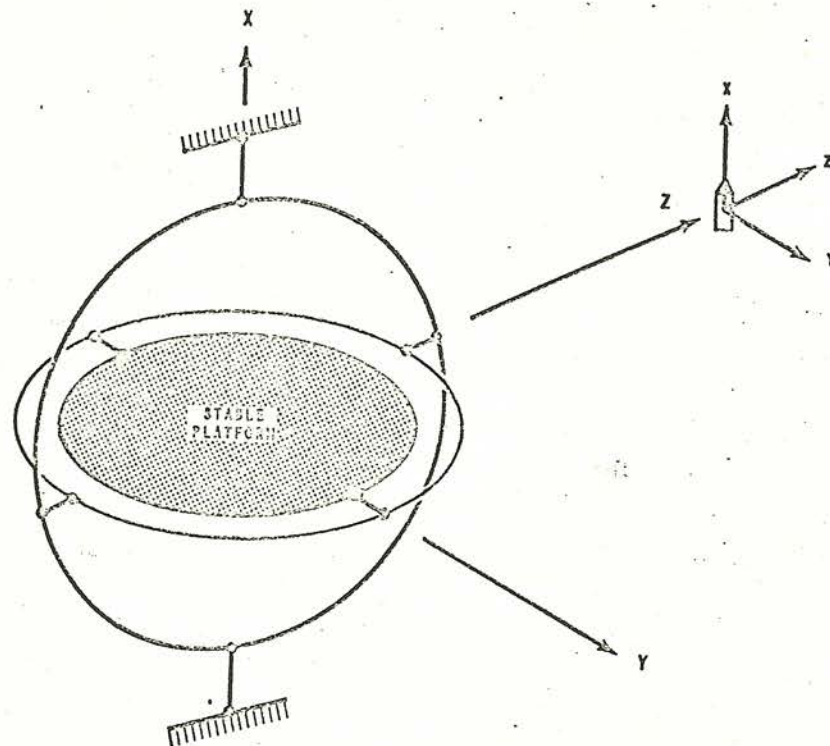
TYPE: Non-rotating, vehicle referenced

ORIGIN: The intersection of the primary axes of
            the accelerometer

ORIENTATION AND LABELING:

        The X axis is parallel to the reference ellipsoid
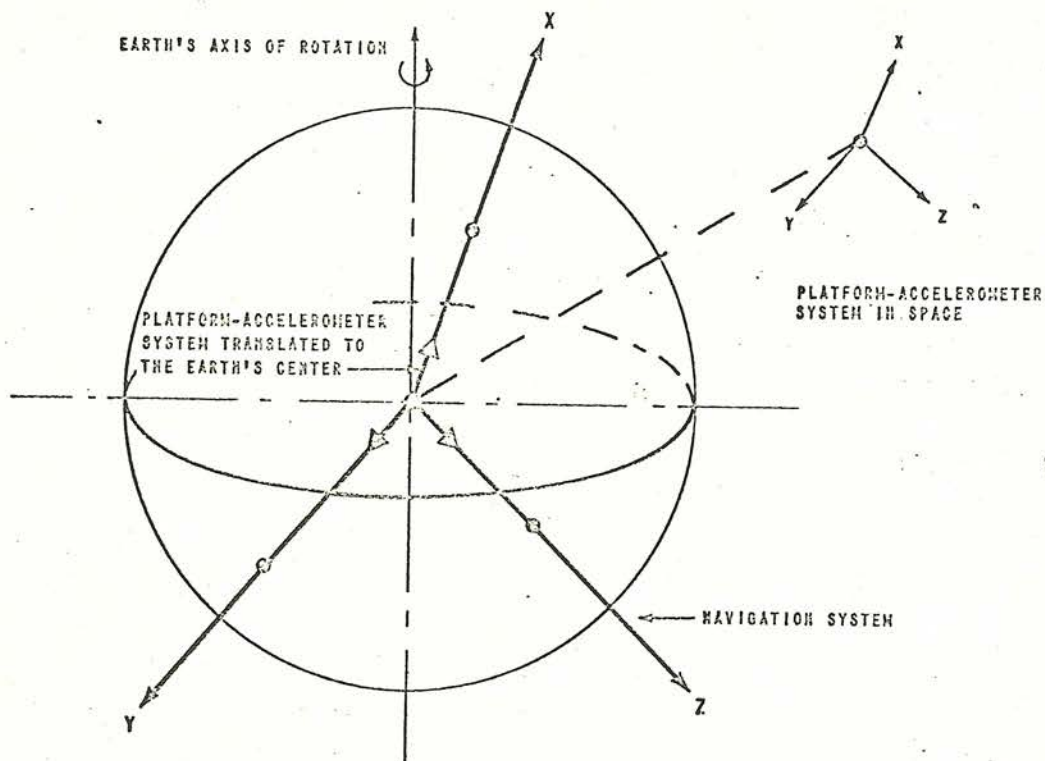   normal through the launch site, positive upward.

        The Z axis is parallel to the aiming azimuth,
        positive downrange.

        The Y axis completes a standard right-handed system.

        This system is translatable with the Earth-Fixed
        Launch Site system at guidance reference release
        time.

FIGURE A-12

STANDARD COORDINATE SYSTEM 13
LAUNCH VEHICLE NAVIGATION

FIGURE A-13

TYPE: Non-rotating, Earth referenced

ORIGIN: The center of the Earth

ORIENTATION AND LABELING:

This system is translatable from the Launch Vehicle Platform-Accelerometer system at guidance reference release for the launch vehicle.

The X axis is parallel to the X axis of the Launch Vehicle Platform-Accelerometer system.

The Y axis is parallel to the Y axis of the Launch Vehicle Platform-Accelerometer system.

The Z axis completes a standard right-handed system.

7.

APPENDIX B

Project Apollo Standard Relationships Existing
Among Standard Coordinate Systems

This Appendix contains the figures depicting
the three Standard Relationships.

LIST OF PROJECT APOLLO STANDARD RELATIONSHIPS

B-1   Dynamical Body Axes Systems

B-2   The Orientation of the Launch
Vehicle, CSM and LEM Structural
Body Axes in the Launch Configuration

B-3   Space Vehicle Structural Body Axes
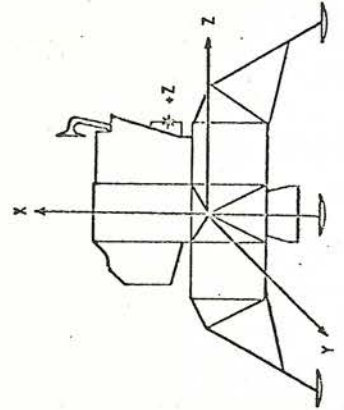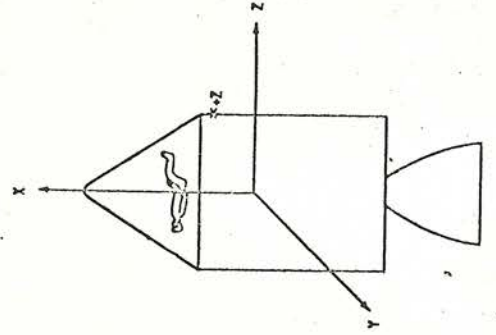
STANDARD RELATIONSHIP 1
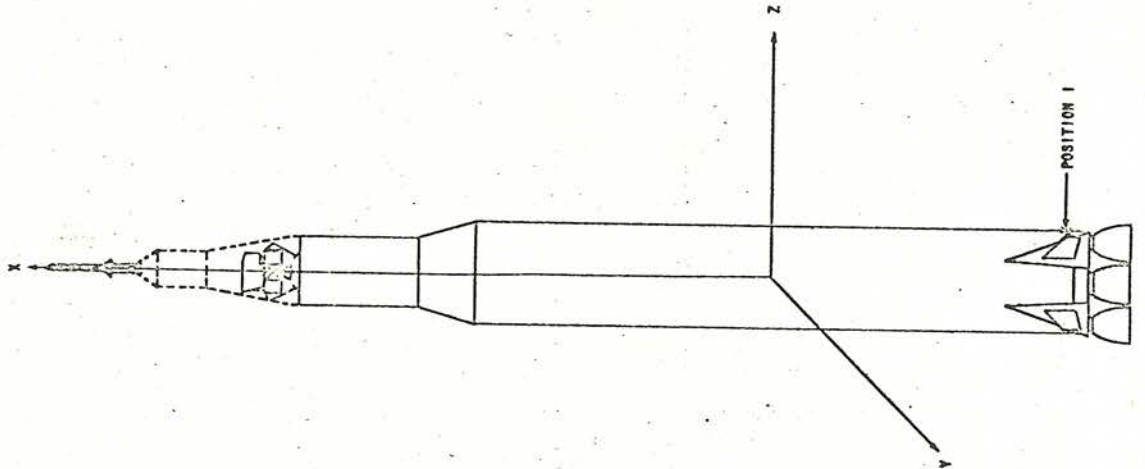
DYNAMICAL BODY AXES SYSTEMS

NOTE: THE DYNAMICAL BODY AXES ARE STANDARDIZED IN THE
SENSE THAT THE POSITIVE Z AXIS IS THE PREFERRED
DOWN RANGE DIRECTION FOR EACH VEHICLE, WHEN
OPERATING INDEPENDENTLY.

COMMAND AND SERVICE MODULE

LUNAR EXCURSION MODULE

LAUNCH VEHICLE

FIGURE B-1

STANDARD RELATIONSHIP 2

THE ORIENTATION OF THE LAUNCH VEHICLE, CSM AND LEM
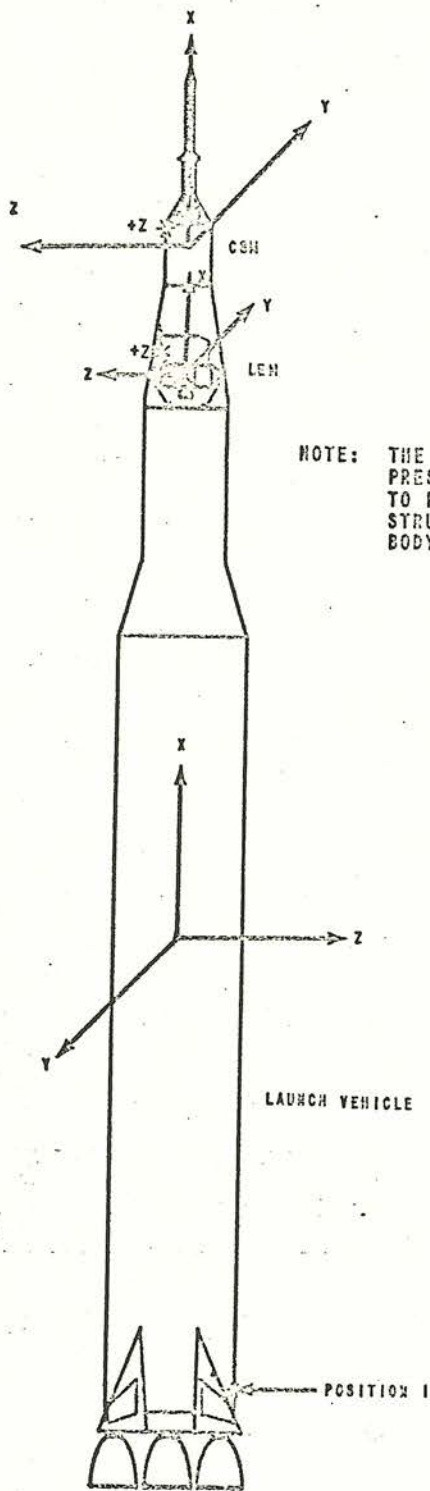STRUCTUAL BODY AXES IN THE LAUNCH CONFIGURATION

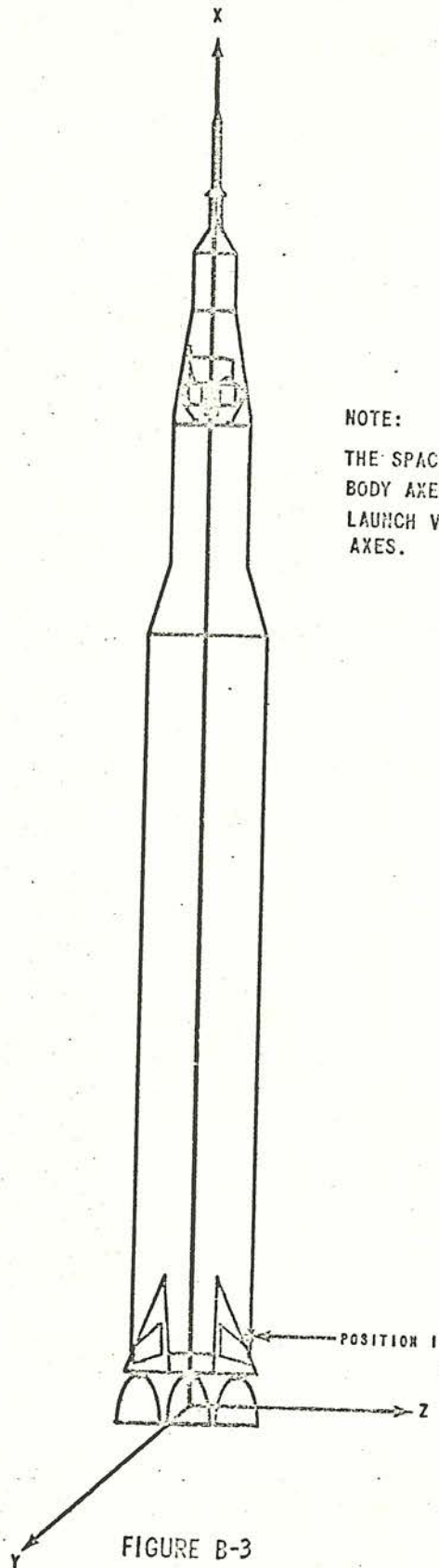NOTE: THE DYNAMICAL BODY AXES ARE
PRESENTED HERE IN ORDER
TO PRESERVE CLARITY. THE
STRUCTURAL AND DYNAMICAL
BODY AXES ARE TRANSLATABLE

FIGURE B-2

X

NOTE:

THE SPACE VEHICLE STRUCTURAL
BODY AXES ARE IDENTICAL WITH
LAUNCH VEHICLE STRUCTURAL BODY
AXES.

POSITION I

Z

Y

FIGURE B-3

8. <u>REFERENCES</u>

1. "AFMTC Standardized Theoretical Trajectory Magnetic Tape Format", Headquarters Air Force Missile Test Center, AFMTCM 80-4, January 5, 1964.

2. "Goddard Directory of Tracking Station Locations," Goddard Space Flight Center, X-544-64-176, July 1, 1964

3. "American Standard, Letter Symbols for Aeronautical Sciences", The American Society of Mechanical Engineers, (ASA Y10.7-1954), October, 1954.

4. "Recommendations of Marshall Space Flight Center for Standardization of Coordinate Systems in MSF", MSFC, NASA TM X-54182, March 2, 1965.

5. "Mass Properties Standard", NASA OMSF Program Directive, M-DE 8000.006, Effective June 1, 1963.