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GUIDANCE AND NAVIGATION

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Table of Contents

1. MISSION AND VEHICLE SIMULATION DATA

1.1 Scope

Section 1 is an attempt to summarize all data that are presently being used for flight simulations and rope verification of CMC programs.

Numerical values are recorded in the most widely accepted units and may not be found in the memory explicitly as defined. These values are often re-scaled, units corrected, or combined with other data in the most convenient and/or economical fashion.

Apollo mission and vehicle data for flight AS-207A, CSM-101 have been collected under the following headings:

> Apollo Mission Data (Sec. 1.2) establishes the outlines of the mission in terms of trajectories, attitude histories, etc. Boost phase performance figures for Saturn vehicles are included since they affect monitor and control of the launch configuration by the GN&C System. These data are required for environment simulation and CMC program verification.
>
> CMC Memory Data (Sec. 1.3) contains mission-and vehicle-dependent data that are written directly into the memory of the CMC. Other memory data are referred to in Vol. I, Sec. 3, 4, and 5. The limited erasable section is reserved primarily for storage of computational variables. Those parameters that do not change during flight have been assigned to the fixed section of the memory. Because initial control of reentry attitude is achieved by the guidance system, associated parameters will be included under this heading.
>
> Apollo Spacecraft CSM-101 Data (Sec. 1.4) is a compilation of vehicle characteristics information and mathematic model descriptions which are being used with the mission data for an effective flight simulation. Vehicle configuration, mass properties, dynamic structural data, engine performance, and aerodynamic data are included. This information will not generally appear directly in the CMC program.
>
> Constants and Conversion Factors (Sec. 1.5) will be used directly in CMC programs as well as simulations. The CMC is programmed in the metric set of kilogram, meter, and centisecond (10^{-2} second). Conversion to these units is accomplished by use of the factors defined in this section. Applicable geodetic and geophysical data are included.
>
> Carry-On Data (Sec. 1.6) contains miscellaneous charts and notes hand-carried by the astronauts.
>
> Block II GN&C System Configuration (Sec. 1.7) defines the provisions incorporated in the GN&C System to mechanize the required system operation. A listing is included of the Interface Controlling Documents (ICD's) which are pertinent to an understanding and definition of the operational interfaces between the GN&C System and the S/C, booster, and astronaut.

1.2 Apollo Mission Data

1.2.1 Mission Trajectory

This section will use the following data source: TRW Systems Document #05952-H041-R8-00, "Apollo Mission AS-207/208A Spacecraft Reference Trajectory" dated 7 October 1966.

1.2.2 Nominal CSM/SIVB Separation Attitude Conditions

X_{SC}-axis in the plane of the trajectory, in the directional of the forward horizontal

Y_{SC}-axis along momentum vector $\underline{R}\times\underline{V}$

Z_{SC}-axis points up and parallel to geocentric radius vector

Roll rate	0 degree/second
Pitch rate	0 degree/second
Yaw rate	0 degree/second

1.2.3 Dispersions (3 Sigma) for Nominal Attitude Conditions at Separation

X_{SC}-axis attitude	2 degrees
Y_{SC}-axis attitude	2 degrees
Z_{SC}- axis attitude	2 degrees
Roll rate residual	0.2 degree/second
Pitch rate residual	0.2 degree/second
Yaw rate residual	0.2 degree/second

1.2.4 LM-CSM Docked Orientation

LM-CSM reference dimensions docked orientation	Fig. 1.1

This figure is taken from TRW Systems Document 2131-H005-R8-000, "Apollo Mission Data Specification AS-207/208A" dated 9 June 1966.

1.2.5 SIVB Attitude Maneuver Requirements

Summary of SIVB orbital attitude maneuvers	Table 1.1

This table is taken from U.S. Government Memorandum 66-FM13-238, dated 19 July 1966.

1.2.6 SIVB Engine Shutdown Transients

Thrust decay from 100% to 5% rated thrust	Fig. 1.2
Thrust decay from 5% rated to zero thrust	Fig. 1.3

Cutoff impulse from mainstage cutoff to 5% thrust is derived by multiplying the thrust level at engine cutoff signal by 0.224 second. The deviation about the

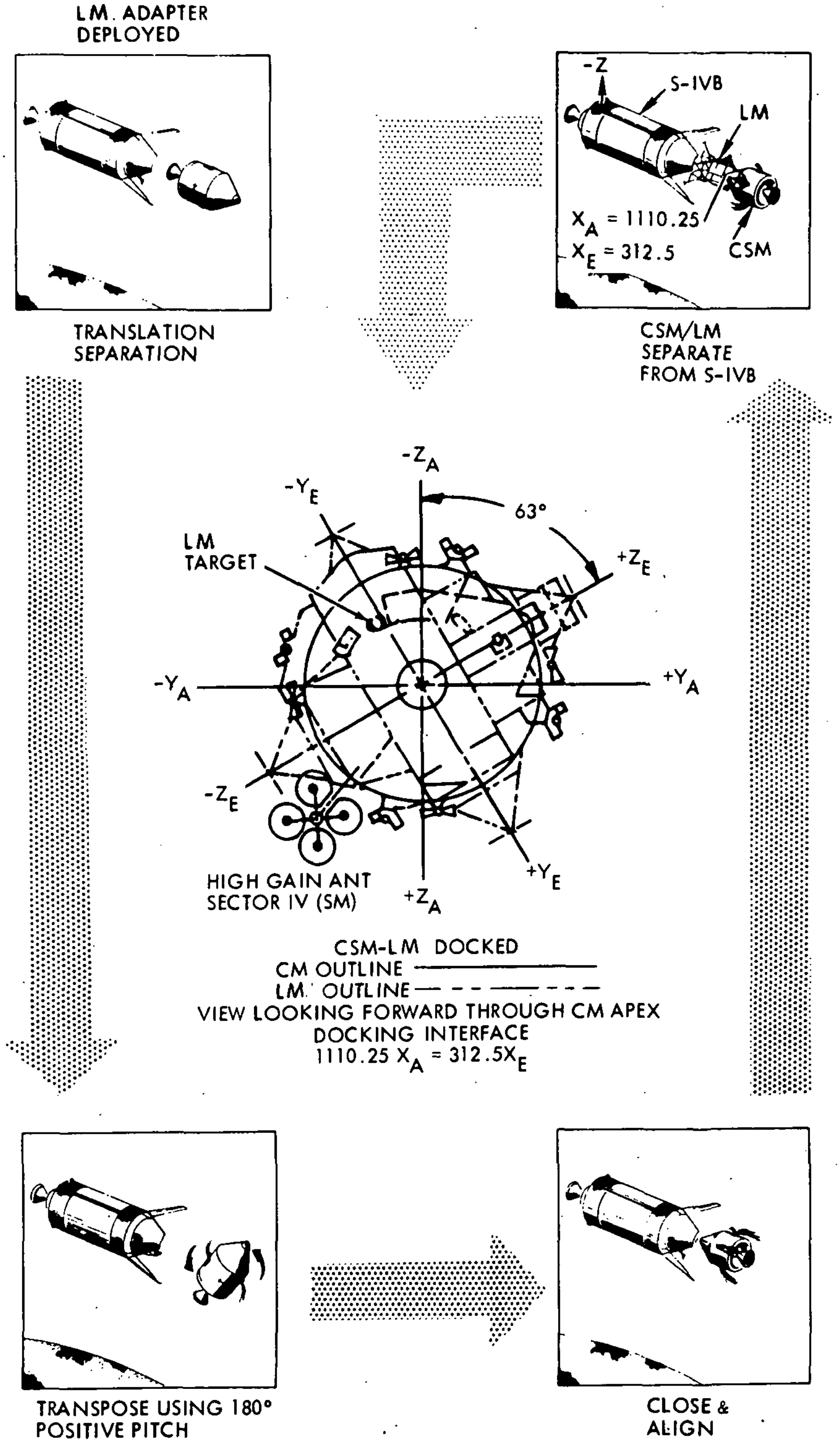


Fig. 1.1 LM-CSM Reference Dimensions Docked Orientation

Table 1.1 Summary of SIVB Orbital Attitude Maneuvers Prior To and After SIVB/Spacecraft Separation for Mission AS-207

Maneuver Description	Approximate Timing of Maneuver	Maneuver Mode	Maneuver Rate	Purpose
Establish zero deg attitude between SC X-axis and local horizontal with the small end forward	Begin immediately after orbital insertion	SIVB computer	0.5	
Maintain SC X-axis alignment with local horizontal - maintain crew heads-down (toward earth) and roll up to ±180 degrees for star acquisition	Begin immediately after completion of previous maneuver	Manual	Average orbit rate	First IMU alignment in darkness
Roll 180 deg to crew heads-up (away from earth) - pitch nose down 20 deg with respect to local horizontal	Start about 1 hour after insertion	Manual	0.5	
Maintain crew heads-up - pitched down 20 deg with respect to local horizontal	Start immediately after completion of previous maneuver	Manual	Average orbit rate	Landmark sighting in daylight
Roll 180 deg to crew heads-down, align SC S-axis with local horizontal small end forward	Start about 2 hours after insertion	Manual	0.5	
Maintain crew heads-down and SC-axis aligned with local horizontal - small end forward and roll up to ± 180 degrees for star acquisition	Start immediately after completion of previous maneuver	Manual	Average orbit rate	Second IMU alignment in darkness

Table 1.1 Summary of SIVB Orbital Attitude Maneuvers Prior To and After SIVB/Spacecraft Separation for Mission AS-207 (Cont'd)

Maneuver Description	Approximate Timing of Maneuver	Maneuver Mode	Maneuver Rate	Purpose
Roll 180 deg to crew heads-up, pitch nose down ___ deg with respect to local horizontal	Start about 140 minutes after insertion	Manual	0.5	Prepare for SIVB/CSM Separation
Maintain crew heads-up and pitched hose down ___ deg with respect to local horizontal	Start immediately after completion of previous maneuver	SIVB computer	Average oribt rate	Prepare for SIVB separation
Establish inertial attitude hold with ± 1 deg deadband	Start shortly before SIVB/SC separation	SIVB computer	Inertially stablized - limit cycle	SIVB/CSM separation
Maintain SIVB roll axis aligned with local horizontal - retrograde attitude - for system lifetime	Start when SIVB roll axis is aligned with local horizontal in retrograde attitude	SIVB computer	Average orbit rate	Force SIVB venting to be in retrograde direction

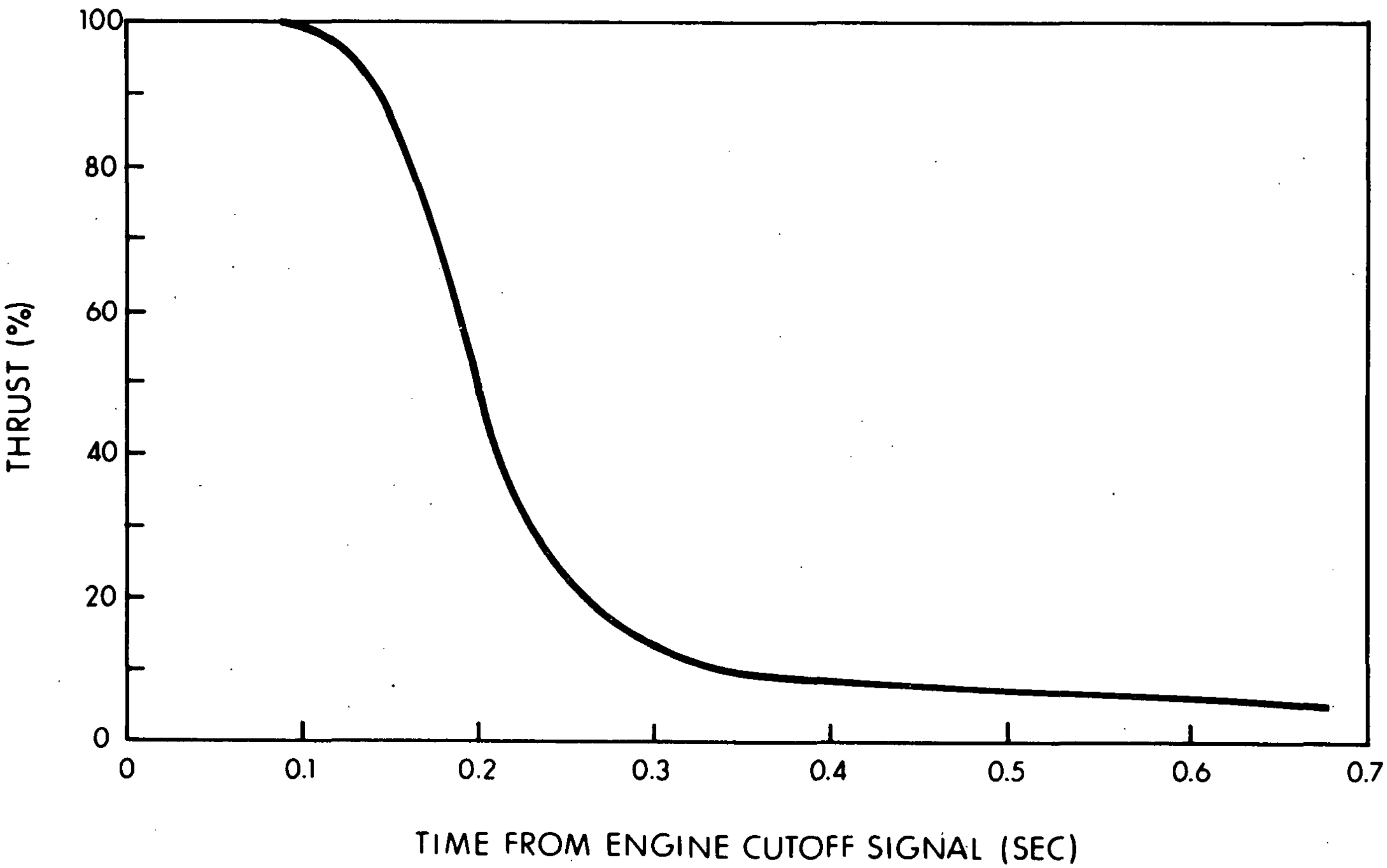


Fig. 1.2 Thrust Decay to 5% Thrust

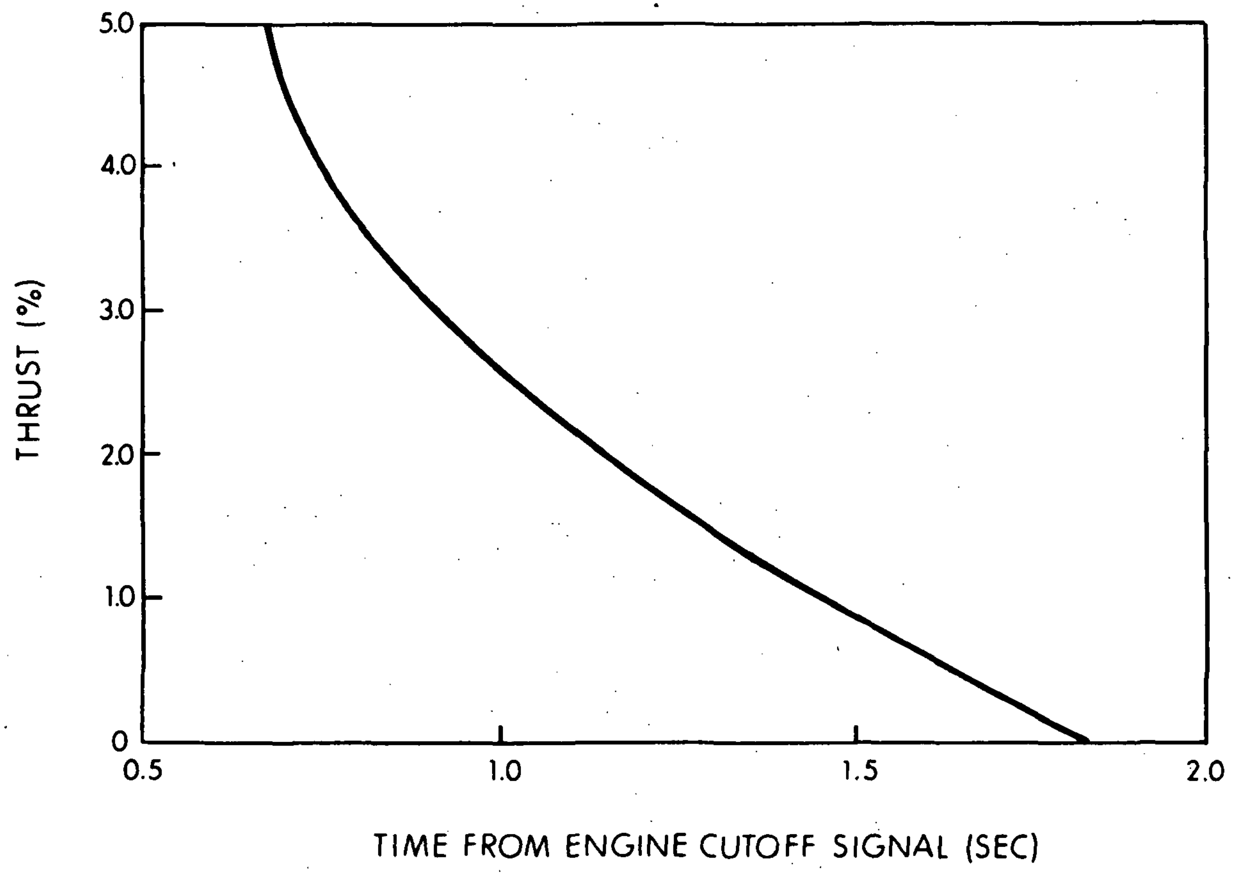
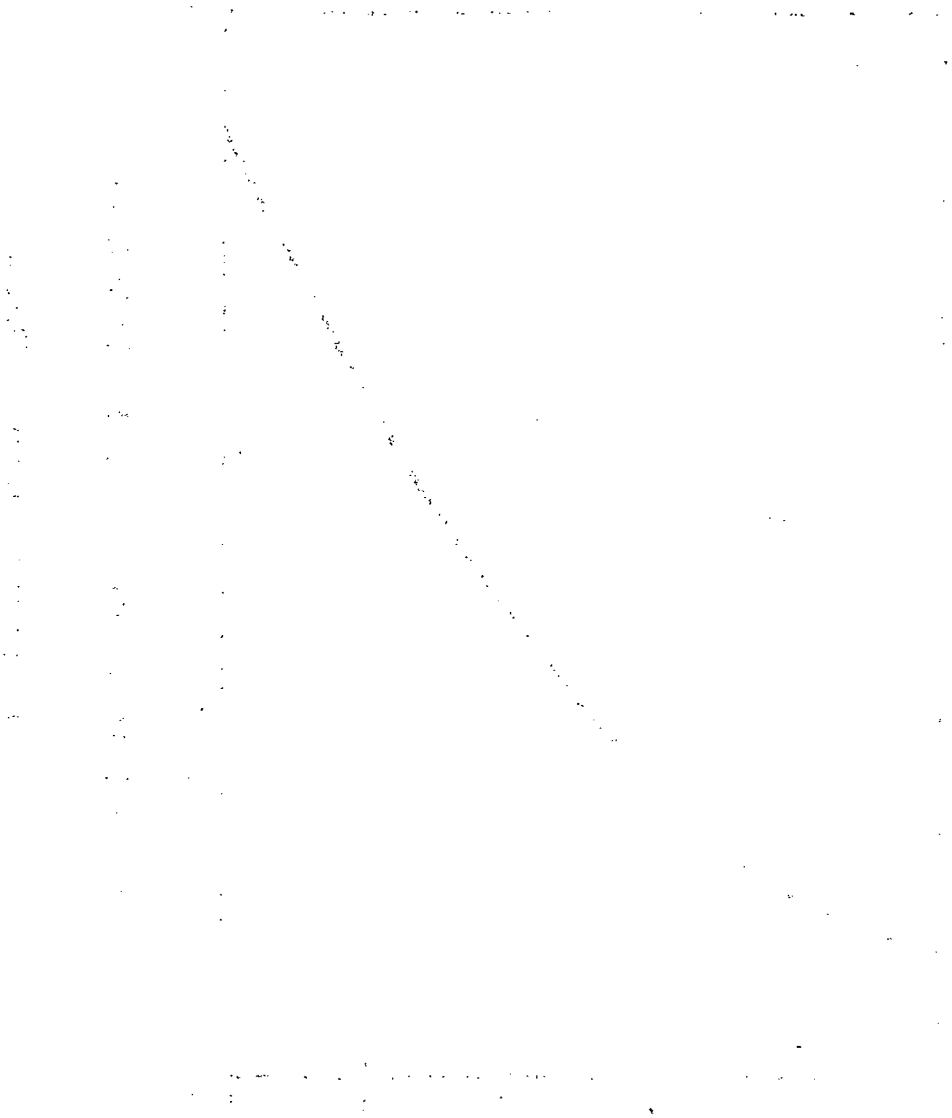


Fig. 1.3 Thrust Decay from 5% Thrust

cutoff impulse is the thrust at cutoff signaltimes ± 0.030 second. The cutoff impulse from 5% thrust is derived by multiplying the thrust level at engine cutoff signal by 0.0235 second.

The information in this section is taken from the GN&C Data Exchange Program, MSC-S-10 submitted 23 August 1966.



1.3 CMC Memory Data

1.3.1 Prelaunch, Launch Pad #34

	Memory	Value
Geodectic latitude	E	28.52196261 °N
Longitude	E	279.4388587 °E
Geocentric radius	E	6373328.10 meters
Geocentric radius to GN&C	E	6373385.0 meters
Fischer Ellipsoid radius	E	6373322.44 meters
Geoidal separation (ht. of MSL above ellipsoid)	E	0 meters
Altitude of pad above MSL	E	5.66 meters
Inertial Reference plane azimuth	E	72° E of True N
Optical target #1: azimuth	E	not available
elevation	E	not available
Optical target #2: azimuth	E	not available
elevation	E	not available

The information in this section is taken from MIT/IL MDRB Record of Change Form #204-2 and #204-6, dated July 1966.

1.3.2 Saturn Launch Vehicle Boost Phase (not available)

		Memory	Value
Interval from liftoff to start of roll maneuver			
Duration of roll maneuver			
Rotation about inertial vertical			
Roll maneuver rate			
Interval from liftoff to start of 1st pitch maneuver			
Duration of 1st pitch maneuver			
Pitch polynomial #1 coefficients	A_0		
	A_1		
	A_2		
	A_3		
	A_4		
	A_5		
	A_6		
Pitch hold period			

NOTE: The form of the pitch polynomials is

$$\theta = \sum_{n=0}^{6} A_n t^n$$

where

θ = angle between the inertial horizontal at launch and the vehicle x-axis, in degrees

t = time, in seconds (t = 0 at liftoff + 10 seconds)

1.3.3 Attitude Maneuver Memory Data

Attitude maneuver constants will be found in the CSM Digital Autopilot (DAP) section of this document. Later issue will indicate fixed or erasable location.

1.3.4 TVC Memory Data

Refer to DAP section. Later issue will indicate fixed or erasable location.

1.3.5 Vehicle Memory Data

Refer to DAP section. Later issue will indicate fixed or erasable location.

1.3.6 Programmed Time Delays

The preset delays between events are outlined in Section 4. Some of these delays are in fixed memory and some in erasable memory. (Erasable memory delays are underlined).

1.3.7 Guidance, Navigation, and Control Constants

The constants used in the guidance, navigation, and control equations are presented in Section 5. These constants are in the fixed portion of the memory.

1.3.8 Navigational Star Memory Data

Star List Table 1.2

The X and Z component for each star appear directly in the CMC fixed memory. The Y-component of the coordinate system is such as to make $X^2 + Y^2 + Z^2 = 1$, where X, Y, and Z are the components of a unit vector pointing from the center of the sun to the star, as of the first of the Besselian year occuring nearest to the launch date. The Z-axis of the coordinate system is in the direction of the mean axis of rotation of the earth. The X-axis is in the direction of the First of Aries at the beginning of the above-defined Besselian year.

Table 1.2 star locations are not corrected for light aberration due to apparent motion. Please note that these locations are only valid for launch dates before 30 June 1967. Should the launch schedule slip, new star locations would have to be determined based upon the first of the following Besselian year.

TABLE 1.2

List of Navigational Stars

Catalogue No.	Star Name	Vis. Mag.	X-Coordinate	Z-Coordinate
1	α Andromedae	2.1	+.8749977835	+.4834543831
2	β Ceti	2.2	+.9342766919	-.3118204677
3	γ Cassiopeiae	2.2	+.4778163663	+.8707281164
4	α Eridani (chernar)	0.6	+.4915952791	-.8425295521
5	α Vrsae Minoris (Polaris)	2.1	+.0132924695	+.9998811678
6	θ Eridani	3.4	+.5451054508	-.6486308798
7	α Ceti	2.8	+.7036628373	+.0690909398
8	α Persei	1.9	+.4110342064	+.7632092298
9	α Tauri (Aldebaran)	1.1	+.3513220851	+.2830955087
10	β Orionis (Rigel)	0.3	+.2016499958	-.1432918501
11	α Aurigae (Capella)	0.2	+.1377394981	+.7189404763
12	α Carinae (Canopus)	-0.9	-.0614208380	-.7952210910
13	α Canis Majoris (Sirius)	-1.6	-.1816329189	-.2868464540
14	α Canis Minoris (Procyon)	0.5	-.4113133007	+.0925568062
15	γ Velorum	1.9	-.3609931072	-.7342632776
16	ι Ursae Majoris	3.1	-.4653358879	+.7451183057
17	α Hydrae	2.2	-.7739264992	-.1480483301
18	α Leonis	1.3	-.8604721512	+.2101000555
19	β Leonis	2.2	-.9655563162	+.2546897675
20	γ Corvi	2.8	-.9526583141	-.2983240329
21	α Crucis	1.6	-.4527184611	-.8903029440
22	α Virginis (Spica)	1.2	-.9173190919	-.1906115874
23	η Ursae Majoris	1.9	-.5812423650	+.7601085228
24	θ Centauri	2.3	-.6903482150	-.5906851838

TABLE 1.2 (Cont'd)

List of Navigational Stars

Catalogue No.	Star Name	Vis. Mag.	X-Coordinate	Z-Coordinate
25	α Bootis (Arcturus)	0.2	-.7864532894	+.3313726156
26	α Coronae Borealis	2.3	-.5331115195	+.4512426836
27	α Scoroii (Antares)	1.2	-.3524228976	-.4440010779
28	α Trainguli Austr.	1.9	-.1152242526	-.9333826927
29	α Ophiuchi	2.1	-.1131188071	+.2178504476
30	α Lyrae (Vega)	0.1	+.1212941902	+.6259631466
31	α Sagittarii	2.1	+.2061438978	-.4436978290
32	α Aguilae (Altair)	0.9	+.4530918807	+.1526503866
33	β Capricorni	3.2	+.5513451257	-.2569243340
34	α Pavonis	2.1	+.3195525649	-.8372001458
35	α Cygni (Deneb)	1.3	+.4538746926	+.7091362137
36	ϵ Pegasi	2.5	+.8136287389	+.1689012500
37	α Piscis Austr. (Fomalhaut)	1.3	+.8339640287	-.4960787198

1.3.9 Reentry Memory Data

CSM attitude for CM/SM separation:

X_{SC}-axis above the velocity vector by	60°
Y_{SC}-axis along momentum vector $\underline{R} \times \underline{V}$	
Z_{SC}-axis above velocity vector	

CM preentry trim attitude:

X_{SC}-axis above velocity vector by	158°
Y_{SC}-axis along momentum vector $\underline{R} \times \underline{V}$	
Z_{SC}-axis above velocity vector	
(Assume a lift-vector up attitude)	
Trim angle of attack	22°

Nominal recovery point:

Latitude (geodetic)	not available
Longitude	not available

A listing of: (1) computer variables in CMC erasable memory, and (2) constants and gains in CMC fixed memory, may be found in the CM Reentry Guidance section of this document.

1.4 Apollo Spacecraft CSM-101 Data

1.4.1 Apollo Vehicle Coordinate Reference System

Spacecraft CSM-101 reference dimensions Fig. 1.4

This figure is taken from TRW System Document 2131-H005-R8-000, "Apollo Mission Data Specification C AS-207/208 A" dated 9 June 1966.

SM, RCS, SPS, and fuel tank configuration Fig. 1.5

Source unknown.

1.4.1.1 Specific Station Locations

RCS jet thruster locations and vectors Table 1.3

The information in this table is compiled from the GN&C Data Exchange Program, NAA-S-22 submitted 7 April 1966.

SPS fuel and oxidizer tank dimensions and locations Table 1.4

The information in this table is taken from the GN&C Data Exchange Program, NAA-S-68 submitted 11 March 1966. modified for a 1.6 mixture ratio.

SPS engine gimbal plane

X_A location	833.200 inches
Y_A location	0.0 inch
Z_A location	0.0 inch

The information is taken from the GN&C Data Exchange Program, NAA-S-68 submitted 11 March 1966.

1.4.2 Apollo Vehicle Mass Property Data

CSM spacecraft mass properties summary	Table 1.5
SM vehicle mass properties summary	Table 1.6
CSM spacecraft propellant loading summary	Table 1.7
SM-RCS usable propellant data	Fig. 1.6
SM-SPS usable propellant	Table 1.8

The information in this section is taken from TRW Systems Document 2131-H005-R8-000, "Apollo Mission Data Specification C AS-207/208A" dated 9 June 1966. The values that actually appear in the simulation program are marked with this characteristics: #?

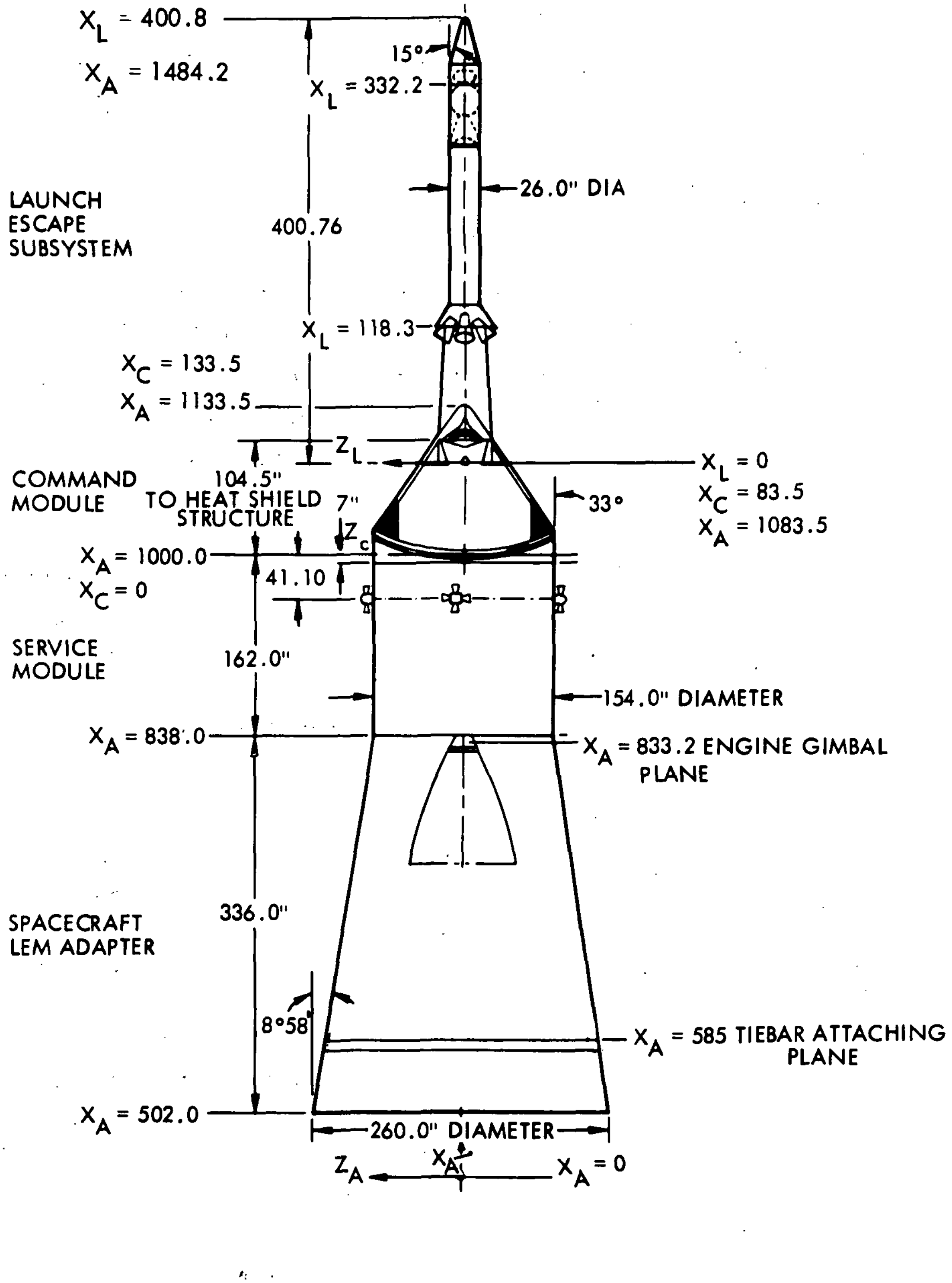


Figure 1.4 AS-207 Apollo Spacecraft (with CSM-101) Reference Dimensions

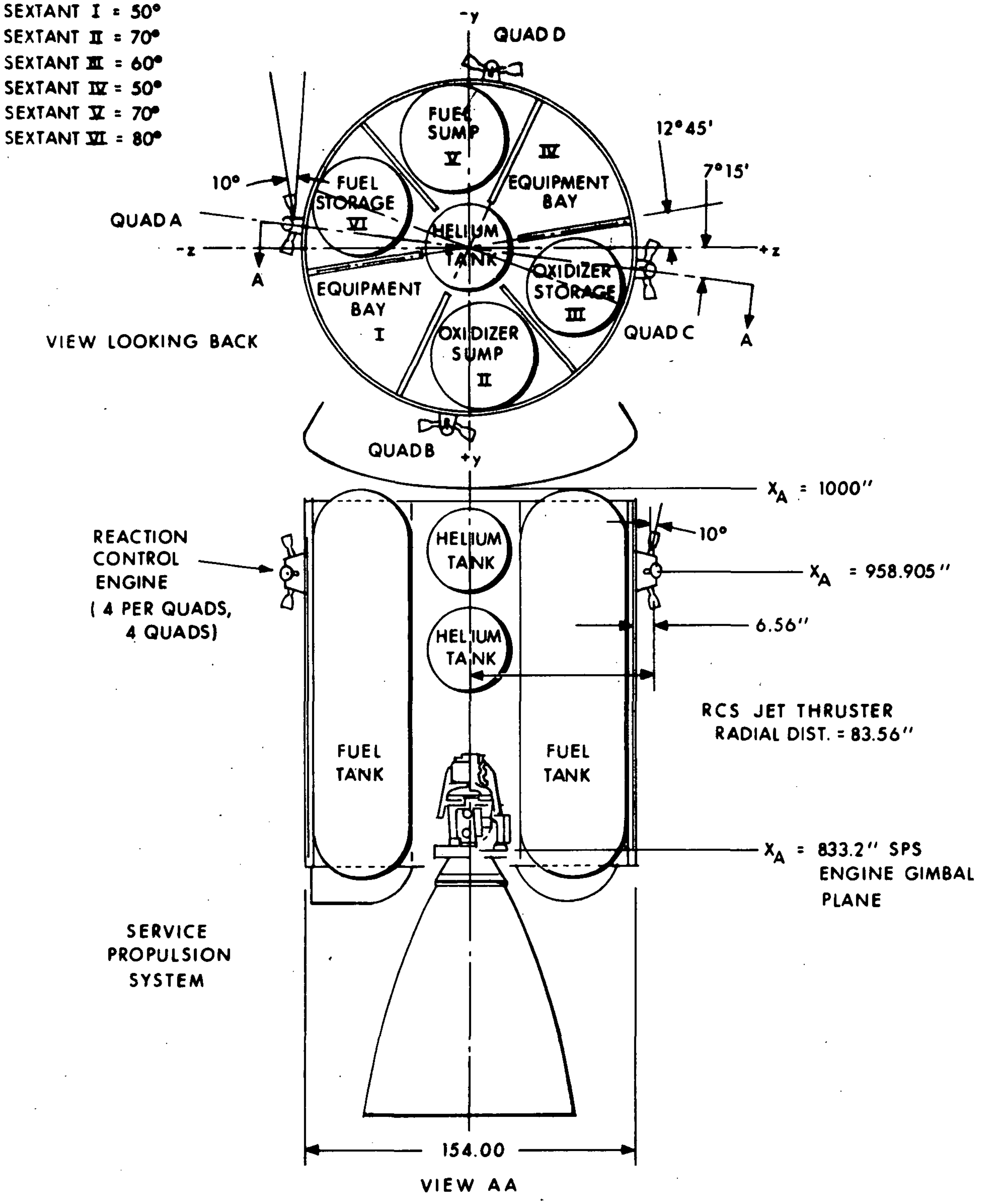


Fig. 1.5 Service Module RCS, SPS and Fuel Tank Configuration

Table 1.3 RCS Jet Thruster Locations and Vectors

Apollo Stations of Four Jet Quads	X_A - Component in Inches	Y_A - Component in Inches	Z_A - Component in Inches
Quad A	958.905	-83.56 sin (7.25°)	-83.56 cos (7.25°)
Quad B	958.905	83.56 cos (7.25°)	-83.56 sin (7.25°)
Quad C	958.905	83.56 sin (7.25°)	83.56 cos (7.25°)
Quad D	958.905	-83.56 cos (7.25°)	83.56 sin (7.25°)

Thrust Unit Vector*	X - Component	Y - Component	Z - Component
RCS Jet 1, Quad C	cos (10°)	0	-sin (10°)
2, Quad A	cos (10°)	0	sin (10°)
3, Quad A	-cos (10°)	0	sin (10°)
4, Quad C	-cos (10°)	0	-sin (10°)
5, Quad D	cos (10°)	sin (10°)	0
6, Quad B	cos (10°)	-sin (10°)	0
7, Quad B	-cos (10°)	-sin (10°)	0
8, Quad D	-cos (10°)	sin (10°)	0
9, Quad B	0	-sin (10°)	cos (10°)
10, Quad D	0	sin (10°)	cos (10°)
11, Quad D	0	sin (10°)	-cos (10°)
12, Quad B	0	-sin (10°)	-cos (10°)
13, Quad A	0	cos (10°)	sin (10°)
14, Quad C	0	cos (10°)	-sin (10°)
15, Quad C	0	-cos (10°)	-sin (10°)
16, Quad A	0	-cos (10°)	sin (10°)

*Thrust vectors are specified as though the guad centers were on the Apollo Y and Z axes.

Table 1.4 SPS Fuel and Oxidizer Tank Dimensions and Locations

Tank Position in Spacecraft's X_A, Y_A, Z_A Coordinates*	Radius in inches	X_A - Top in inches	X_A - Bottom in inches	Y_A in inches	Z_A in inches
V Fuel Sump Tank	25.5	985.8	832.0	-48.3	-6.6
II Oxidizer Sump Tank	25.5	985.8	832.0	48.3	6.6
VI Fuel Storage Tank	22.5	988.65	832.0	-14.8	-47.8
III Oxidizer Storage Tank	22.5	988.65	832.0	14.8	47.8

*Mixture ratio = 1.6

Table 1.5 AS-207A Spacecraft (With CSM-101) Mass Properties Summary[(1)]

	Weight (lb)	Center of Gravity[(2)] (in.)			Moments of Inertia[(3)] (slug-ft^2)			Products of Inertia[(3)] (slug-ft^2)		
		X_A	Y_A	Z_A	I_{xx}	I_{yy}	I_{zz}	I_{xy}	I_{xz}	I_{yz}
Spacecraft Systems/Subsystem										
Launch Escape Subsystem	8,300 ± 106	1,298.7 ± 1.0	-0.1 ± 0.5	-0.3 ± 0.5	617	22,355	22,354	54	175	1
#? - **Command Module**[(4)]	11,510 ± 520	1,041.9 ± 1.0	0.2 ± 0.5	5.6 ± 0.5	5,597	4,950	4,491	0	-338	17
Service Module	22,835 ± 436	894.8 ± 0.8	3.5 ± 0.4	5.7 ± 0.4	13,104	15,059	21,037	-1,033	891	411
SLA	3,755 ± 156	634.7 ± 1.0	1.8 ± 0.5	1.0 ± 0.5	9,659	12,262	11,990	-77	69	67
Spacecraft (W/CSM-101) at Liftoff	46,400 ± 705	982.5 ± 1.7	1.9 ± 0.2	4.2 ± 0.2	29,065	378,597	383,810	-3,106	-1,300	519
Remove LES	-8,300 ± 106	1,298.7 ± 1.0	-0.1 ± 0.5	-0.3 ± 0.5	-617	-22,355	-22,354	-54	-175	-1
Spacecraft (W/CSM-101) in Earth Orbit	38,100 ± 697	913.6 ± 2.2	2.3 ± 0.3	5.2 ± 0.3	28,395	137,988	143,238	-1,779	1,651	498
Remove SLA	-3,755 ± 156	634.7 ± 1.0	1.8 ± 0.5	1.0 ± 0.5	-9,659	-12,262	-11,990	77	-69	-67
CSM-101 in Earth Orbit	34,345 ± 679	944.1 ± 1.6	2.4 ± 0.3	5.7 ± 0.3	18,719	55,778	61,315	-1,837	524	429
#? - **Add LEM 2 (Unmanned, Docked)**	33,005 ± 580	1,234.6 ± 1.0	0.4 ± 0.5	1.5 ± 0.5	23,025	26,097	26,061	-4	194	92
CSM-101/LEM 2 Docked in Orbit	67,350 ± 893	1,086.4 ± 1.8	1.4 ± 0.3	3.6 ± 0.3	41,823	388,514	393,965	-3,315	-6,543	556

Notes: (1) All tolerances shall be used as 3σ values.

(2) Centers of gravity are referenced to the Apollo spacecraft coordinate system origin.

(3) Moments and products of inertia are about the enter of gravity of each item. Tolerance on moments and products of inertia is ± 10 percent.

(4) Includes 225 pounds of usable propellant and 45 pounds of residuals. Residual quantity is based on an estimate of 1.0 pound of H_e, 30.8 pounds of propellant trapped in engine, 2.7 pounds of mixture ratio uncertainty, 2.7 pounds of loading uncertainty and 7.8 pounds of tank efficiency.

Two man crew transfer out of command module: weight (lb) = 600; center of gravity (in.) $X_A = 1043.0$, $Y_A = -1.4$, $Z_A = -10.8$; moment of inertia (slug-ft^2) $I_{xx} = 95$, $I_{yy} = 81$, $I_{zz} = 127$.

#? -: The numbers actually used in the simulation.

Table 1.6 AS-207A Service Module (CSM-101) Mass Properties Summary

	Weight (lb)	Center of Gravity(1) (in.)			Moments of Inertia(2) (slug-ft^2)			Products of Inertia(2) (slug-ft^2)		
		X_A	Y_A	Z_A	I_{xx}	I_{yy}	I_{zz}	I_{xy}	I_{xz}	I_{yz}
#? – Service Module, Inert(3)	9,485	911.1	-6.2	11.8	5,719	10,670	10,615	-367	555	-200
#? – SLA Attach Ring	75	837.1	0.0	-1.8	93	48	46	0	0	0
SPS Usable Propellant	12,485	878.6	11.1	1.5	6,062	1,751	7,592	23	4	814
RCS Usable Propellant	790	959.0	0.0	0.0	750	450	425	0	0	0
Total Service Module(4)	22,835 ± 436	894.8 ± 0.8	3.5 ± 0.4	5.7 ± 0.4	13,104	15,059	21,037	-1,034	891	411

Notes: (1) Centers of gravity are referenced to the Apollo spacecraft coordinate system origin.

(2) Moments and products of inertia are about the center of gravity of each item.

(3) Includes 48 pounds of RCS residuals based on an estimate of 3.0 pounds of H_e, 3.8 pounds of propellant trapped in engine, 8.8 pounds of mixture ratio uncertainty, 8.4 pounds of loading uncertainty, and 24.0 pounds of tank efficiency.

Includes 834 pounds of SPS residuals based on an estimate of 88 pounds of H_e, 2 pounds of N_2, 80 pounds of tank vapor, 159 pounds of propellant in retention reservoir, 125 pounds of propellant in plumbing, 77 pounds of propellant trapped in engine, 110 pounds of mixture ratio uncertainty and 193 pounds of loading uncertainty.

(4) Tolerances shall be used as 3σ values.

#? -: The numbers actually used in the simulation.

Table 1.7 Spacecraft Propellant Loading Summary

	Weight (lb)	Center of Gravity[(1)] (in.)			Moments of Inertia[(2)] (slug-ft^2)			Products of Inertia[(2)] (slug-ft^2)		
		X	Y	Z	I_{xx}	I_{yy}	I_{zz}	I_{xy}	I_{xz}	I_{yz}
AS-207A										
Command and Service Module (CSM-101)										
#? - **SPS Usable Propellant**(3)	12,485	878.6	11.1	1.5	See Table 1.8			See Table 3-5		
CM RCS Usable Propellant(4)(5)	225	1,022.6	-5.6	57.0	See Figure 1.8			0	0	0
#? - **SM RCS Usable Propellant**(4)(5)	790	959.0	0.0	0.0	See Figure 1.6			0	0	0

Notes: (1) CSM propellant centers of gravity are referenced to the Apollo spacecraft coordinate system origin.

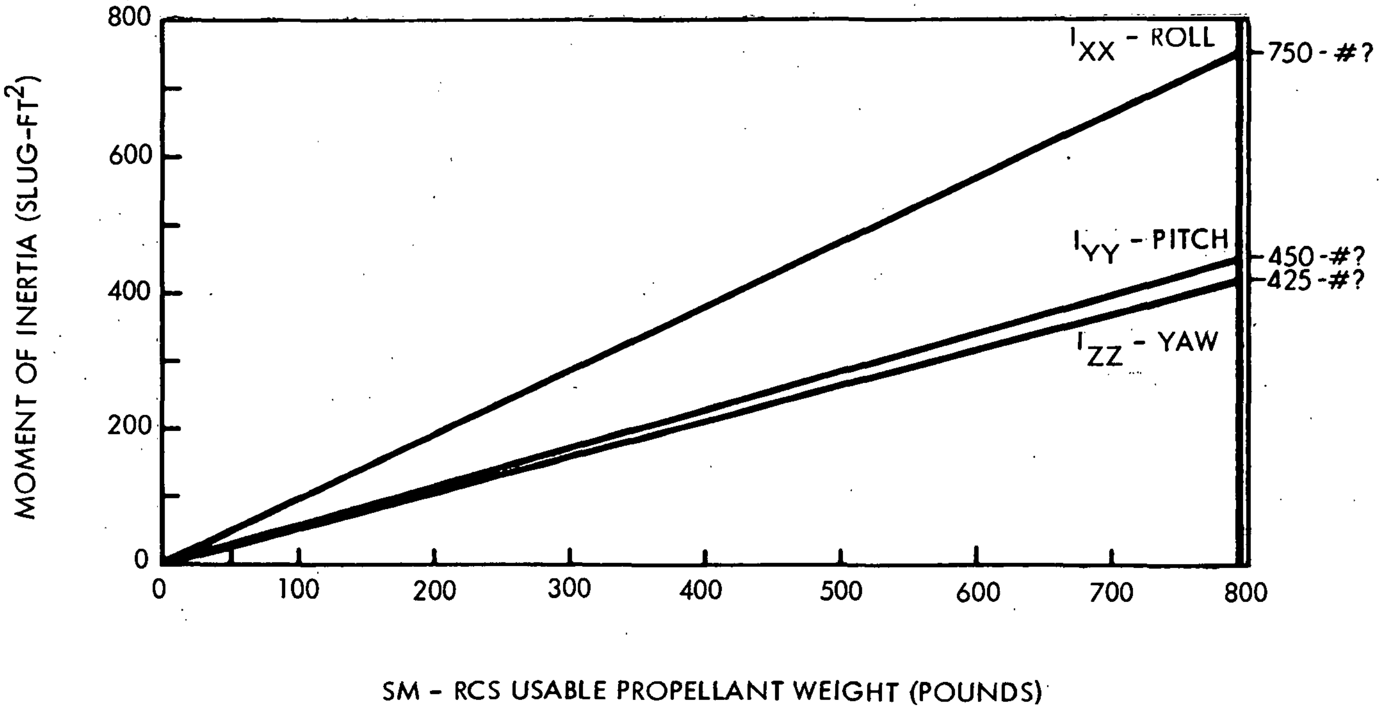
(2) Moments and products of inertia are about the center of gravity of each item.

(3) Usable quantities are based on O/F ratio of 1.6:1.

(4) Usable quantities are based on O/F ratio of 2:1.

(5) Center of gravity remains constant through usable propellant consumption.

#? -: The numbers actually used in the simulation.



Notes: The propellant center of gravity is presented in Table 1.7 and remains constant. Moments of inertia are about propellant center of gravity.

#? -: The numbers actually used in the simulation.

Fig. 1.6 SM-RCS Usable Propellant Mass Properties

Table 1.8 AS-207A Module (CSM-101) Usable SPS Propellant Mass Properties

	Weight (lb)	Center of Gravity[1] (in.)			Moments of Inertia[2] (slug-ft^2)			Products of Inertia[2] (slug-ft^2)		
		X_A	Y_A	Z_A	I_{xx}	I_{yy}	I_{zz}	I_{xy}	I_{xz}	I_{yz}
	400.3	842.4	11.4	1.4	194.6	17.2	204.7	1.0	0.1	26.0
	800.4	843.3	11.3	1.6	388.9	35.7	410.3	1.7	0.2	52.1
	1,200.4	844.9	11.2	1.5	583.1	54.5	616.2	2.4	0.3	78.2
	1,600.4	846.3	11.2	1.5	777.3	74.1	822.9	3.0	0.5	104.2
	2,000.4	847.6	11.3	1.5	971.9	94.9	1,031.2	3.7	0.5	130.3
	2,402.1	848.9	11.2	1.5	1,166.5	116.7	1,240.5	4.3	0.7	156.4
	2,802.1	850.2	11.2	1.6	1,360.7	140.1	1,450.9	5.0	0.7	182.5
	3,202.1	851.3	11.2	1.6	1,555.0	165.1	1,663.1	5.6	0.7	208.5
	3,602.1	852.6	11.2	1.6	1,749.2	191.8	1,876.9	6.2	0.9	234.6
	4,002.9	853.7	11.2	1.6	1,943.4	220.7	2,092.9	6.9	0.9	260.1
#? -	4,402.1	854.9	11.2	1.6	2,137.6	251.9	2,311.3	7.6	1.0	286.7
	4,802.1	856.2	11.2	1.6	2,332.0	285.5	2,531.9	8.3	1.2	312.8
	5,202.1	857.4	11.2	1.6	2,526.2	322.0	2,755.6	8.9	1.2	338.8
	5,602.1	858.6	11.2	1.6	2,720.5	361.6	2,982.3	9.6	1.4	364.9
	6,002.1	859.6	11.1	1.5	2,914.6	404.7	3,212.6	10.4	1.6	390.9
	6,402.1	860.8	11.1	1.5	3,108.9	451.0	3,446.0	11.1	1.7	417.0
	6,802.1	862.0	11.2	1.5	3,303.1	501.0	3,683.1	11.8	1.7	443.1
	7,202.1	863.2	11.2	1.5	3,497.4	555.0	3,924.2	12.5	1.9	469.1
	7,602.1	864.4	11.2	1.5	3,691.6	613.1	4,169.4	13.3	2.0	495.2
	8,002.1	865.6	11.2	1.5	3,885.9	675.7	4,419.1	14.0	2.1	521.2
#? -	8,402.1	866.7	11.2	1.5	4,080.1	743.4	4,673.9	14.6	2.2	547.3
	8,802.1	867.9	11.2	1.5	4,274.3	815.4	4,933.0	15.5	2.4	573.3
	9,202.1	869.1	11.2	1.5	4,468.6	892.5	5,197.4	16.2	2.4	599.4
	9,602.1	870.3	11.2	1.5	4,662.8	975.1	5,467.0	17.0	2.6	625.5
	10,002.1	871.4	11.2	1.5	4,857.1	1,063.7	5,742.8	17.7	2.7	651.5
	10,402.1	872.3	11.2	1.5	5,051.3	1,157.6	6,023.8	18.6	2.8	677.6
	10,802.1	873.8	11.2	1.5	5,245.6	1,257.6	6,310.8	19.3	2.9	703.6
	11,202.1	874.9	11.2	1.5	5,439.8	1,363.8	6,604.3	20.2	3.0	729.7
	11,602.1	876.0	11.1	1.5	5,634.1	1,477.1	6,904.7	21.2	3.2	755.7
	12,002.1	877.2	11.1	1.5	5,828.2	1,597.7	7,211.2	22.1	3.3	781.8
#? -	12,402.1	878.4	11.1	1.5	6,022.5	1,723.1	7,524.8	22.9	3.4	807.8
	12,485.0	878.6	11.1	1.5	6,062.0	1,751.0	7,592.0	23.0	4.0	814.0

Notes: (1) Propellant centers of gravity are referenced to the Apollo spacecraft coordinate system origin.

(2) Moments and products of inertia are about the propellant center of gravity.

(3) Mass properties are based on O/F ratio of 1.6:1.

#? -: The numbers actually used in the simulation.

1.4.3 Apollo Vehicle Dynamic Data

1.4.3.1 Slosh (Valid with or without LM) 1.6 Mixture Ratio

Oxidizer slosh mass in storage tanks	24.95 slugs
Oxidizer slosh mass in sump tanks	35.85 slugs
Fuel slosh mass in storage tanks	15.61 slugs
Fuel slosh mass in sump tanks	24.43 slugs
Oxidizer slosh frequency in storage tanks	3.40 rad/sec
Oxidizer slosh frequency in sump tanks	3.88 rad/sec
Fuel slosh frequency in storage tanks	3.40 rad/sec
Fuel slosh frequency in sump tanks	3.88 rad/sec
Corresponding propellant mass in storage tanks	59901 pounds
Corresponding propellant mass in sump tanks	40588 pounds
Oxidizer slosh damping ratio	0.0007
Fuel slosh damping ratio	0.0007

Slosh mass stations for various values of propellant mass:

	Propellant Mass	Oxidizer Mass Station	Fuel Mass Station
Storage Tanks -	38626 pounds	933.7 inches	933.0 inches
	28969 pounds	862.0 inches	861.7 inches
Sump Tanks -	19313 pounds	922.5 inches	922.3 inches
	10043 pounds	869.1 inches	869.0 inches

The information contained in this section is taken from NAA Internal Letter FS/GCA/65-64.

1.4.3.2 Structural Bending Data (LM/CSM Coupled)

First bending mode damping constant	0.005 $\sec^{-1}$
Second bending mode damping constant	0.015 $\sec^{-1}$
Third bending mode damping constant	0.015 $\sec^{-1}$

The above data are unofficial, transmitted to MIT/IL by Mr. Tan Lu (NAA at MIT/IL) in "Data Transmittal #1", dated September 1965.

Bending data for Full CSM - 92,112 lbs.	Table 1.9
Bending data for Three-Quarter-Full CSM - 80,112 lbs	Table 1.10
Bending Data for Half-Full CSM - 71,508 lbs	Table 1.11

The information contained in the above tables is compiled from the GN&C Data Exchange Program, NAA-S-37 submitted 26 August 1965.

TABLE 1.9

CSM Full - 92112 pounds

Frequency of:		
1st bending mode	1.512	cps
2nd bending mode	4.932	cps
3rd bending mode	6.473	cps
Displacement of:		
1st bending mode at thrust station	+0.88	inch/inch
2nd bending mode at thrust station	-0.17	inch/inch
3rd bending mode at thrust station	-0.21	inch/inch
Slope of:		
1st bending mode at thrust station	-0.590	°/inch
2nd bending mode at thrust station	+0.166	°/inch
3rd bending mode at thrust station	+0.210	°/inch
Displacement of:		
1st bending mode at RCS jets	-0.42	inch/inch
2nd bending mode at RCS jets	+0.20	inch/inch
3rd bending mode at RCS jets	+0.25	inch/inch
Displacement of:		
1st bending mode at IMU location	-1.42	inch/inch
2nd bending mode at IMU location	+0.41	inch/inch
3rd bending mode at IMU location	+0.45	inch/inch
Slope of:		
1st bending mode at IMU location	-0.590	°/inch
2nd bending mode at IMU location	+0.106	°/inch
3rd bending mode at IMU location	+0.073	°/inch

TABLE 1.10

CSM 3/4 -Full - 80112 pounds

Frequency of:		
1st bending mode	1.580	cps
2nd bending mode	5.016	cps
3rd bending mode	6.521	cps
Displacement of:		
1st bending mode at thrust station	+0.87	inch/inch
2nd bending mode at thrust station	-0.17	inch/inch
3rd bending mode at thrust station	-0.20	inch/inch
Slope of:		
1st bending mode at thrust station	-0.583	°/inch
2nd bending mode at thrust station	+0.172	°/inch
3rd bending mode at thrust station	+0.197	°/inch
Displacement of:		
1st bending mode at RCS jets	-0.42	inch/inch
2nd bending mode at RCS jets	+0.21	inch/inch
3rd bending mode at RCS jets	+0.23	inch/inch
Displacement of:		
1st bending mode at IMU location	-0.40	inch/inch
2nd bending mode at IMU location	+0.45	inch/inch
3rd bending mode at IMU location	+0.48	inch/inch
Slope of:		
1st bending mode at IMU location	-0.583	°/inch
2nd bending mode at IMU location	+0.125	°/inch
3rd bending mode at IMU location	+0.115	°/inch

TABLE 1.11

CSM 1/2-Full - 71508 pounds

Frequency of:		
1st bending mode	1.651	cps
2nd bending mode	5.087	cps
3rd bending mode	6.545	cps
Displacement of:		
1st bending mode at thrust station	+1.07	inch/inch
2nd bending mode at thrust station	-0.22	inch/inch
3rd bending mode at thrust station	-0.24	inch/inch
Slope of:		
1st bending mode at thrust station	-0.613	°/inch
2nd bending mode at thrust station	+0.186	°/inch
3rd bending mode at thrust station	+0.200	°/inch
Displacement of:		
1st bending mode at RCS jets	-0.28	inch/inch
2nd bending mode at RCS jets	+0.19	inch/inch
3rd bending mode at RCS jets	+0.20	inch/inch
Displacement of:		
1st bending mode at IMU location	-1.32	inch/inch
2nd bending mode at IMU location	+0.46	inch/inch
3rd bending mode at IMU location	+0.46	inch/inch
Slope of:		
1st bending mode at IMU location	-0.613	°/inch
2nd bending mode at IMU location	+0.146	°/inch
3rd bending mode at IMU location	+0.135	°/inch

1.4.3.3 Structural Bending Data (CSM only)

First bending mode damping constant	.005 ft/sec

This constant is unofficial, transmitted to MIT/IL by Mr. Tan Lu (NAA at MIT/IL) in "Data Transmitted #1", dated September 1965.

CSM Bending data for 1st mode only	Table 1.12

The information contained in the table is compiled from the GN&C Data Exchange Program, NAA-S-37 submitted 26 August 1965.

1.4.4 Service Propulsion System (SPS) Data

1.4.4.1 Engine Physical Properties

Mass	25 slugs

The source for the above data is unofficial, telecon with Mr. Jack Potts (NAA/S&ID).

Engine Inertia	246.1 slug-feet^2
Engine c.g. to gimbal	8 inches

This information is taken from the GN&C Data Exchange Program, NAA-S-46 submitted 8 October 1965.

1.4.4.2 Coupling Display Unit (CDU) Data

TVC pulse weight	1.42 arc min/pulse
Pulse train rate	3200 pulse/sec
Optics error counter limit	384 pulses

This information is taken from a MIT CDU writeup by Mr. G. Gilmore (MIT/IL).

1.4.4.3 Gimbal Actuator System (MOD II)

SPS thrust vector orientation	Fig. 1.7

The above figure is taken from TRW Systems Document #2131-H005-R8-000, "Apollo Mission Data Specification C AS-207/208A" dated 9 June 1966.

TABLE 1.12

CSM First Bending Mode Data

CSM - 63,100 pounds

Frequency of 1st bending mode	19.90	cps
Displacement of 1st bending mode at engine gimbal	+0.34	inch/inch
Slope of 1st bending mode at engine gimbal	-0.208	°/inch
Displacement of 1st bending mode at RCS jets	-0.94	inch/inch
Slope of 1st bending mode at RCS jets	-0.417	°/inch
Displacement of 1st bending mode at IMU location	+1.95	inch/inch
Slope of 1st bending mode at IMU location	+0.834	°/inch

CSM - 42,500 pounds

Frequency of 1st bending mode	22.74	cps
Displacement of 1st bending mode at engine gimbal	+0.46	inch/inch
Slope of 1st bending mode at engine gimbal	-0.334	°/inch
Displacement of 1st bending mode at RCS jets	-1.08	inch/inch
Slope of 1st bending mode at RCS jets	-0.584	°/inch
Displacement of 1st bending mode at IMU location	+1.40	inch/inch
Slope of 1st bending mode at IMU location	+0.667	°/inch

CSM - 21,900 pounds

Frequency of 1st bending mode	32.85	cps
Displacement of 1st bending mode at engine gimbal	+1.10	inch/inch
Slope of 1st bending mode at engine gimbal	-0.792	°/inch
Displacement of 1st bending mode at RCS jets	-1.32	inch/inch
Slope of 1st bending mode at RCS jets	-1.042	°/inch
Displacement of 1st bending mode at IMU location	+0.68	inch/inch
Slope of 1st bending mode at IMU location	+0.417	°/inch

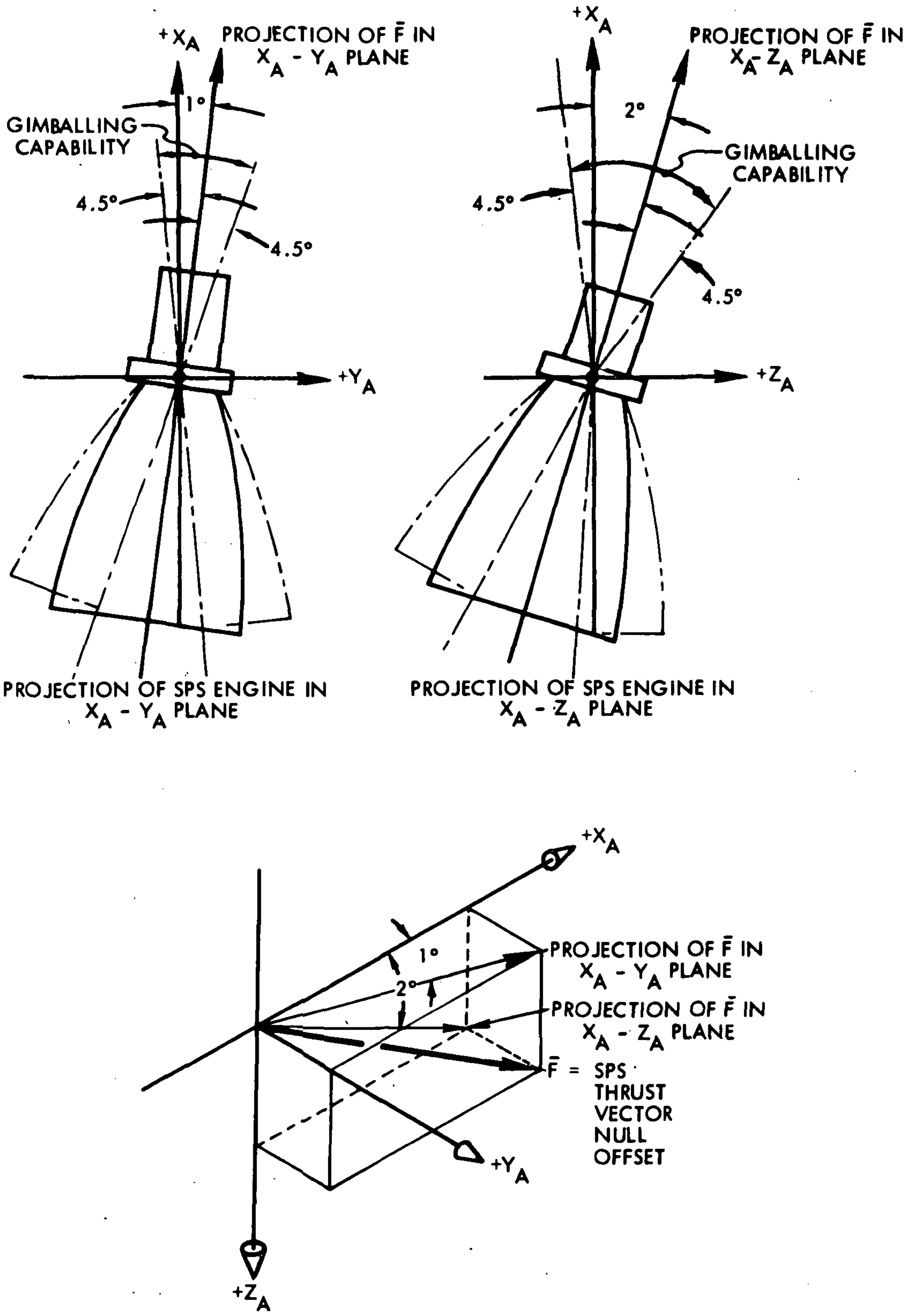


Figure 1.7 Service Propulsion Subsystem (SPS) Thrust Vector Orientation

Gimbal limit	± 4.5 degrees
Pitch gimbal offset*	-2 degrees
Yaw gimbal offset*	+1 degree
Torque limit	1500 ft-pounds
Thrust angular misalignment	1/2 degree
Thrust-to-gimbal offset	1/8 inch

The above information is taken from the GN&C Data Exchange Program, NAA-S-46 submitted 8 October 1965.

*The sign convention is defined in IRN 3604 (dated 8 December 1965) to NAA ICD MH01-1307-206.

Maximum gimbal rate	0.15 rad/sec

The above datum is taken from TRW Systems Document #2131-H005-R8-000, "Apollo Mission Data Specification C AS-207/208A" dated 9 June 1966.

Jet damping coefficient	171 ft-lb-sec
Hose stiffness	285 foot-lb

The above information is taken from the discussions of S&ID/MIT Meeting #66B of 17 September 1963.

Snubber stiffness	$29,400 \frac{\text{foot-lb}}{\text{degree}}$
Actuator damping	1600 foot-lb-sec
Servo amplifier gain	20 amp/rad
Clutch gain	3480 ft-lb/amp
Position feedback gain	1.0 rad/rad
Rate feedback gain	$0.1\ \text{rad}/\frac{\text{rad}}{\text{sec}}$
Actuator inertia	$49.4\ \text{ft-lb-sec}^2$

The above information is taken from the GN&C Data Exchange Program, NAA-S-46 submitted 8 October 1965.

1.4.4.4 SPS Engine Vacuum Performance

Turn on step delay $(\Delta T_{\text{Build Up}})$		0.37 second
Build up impulse to 90% rated thrust		300 ± 200 lb-sec
Thrust build up vs. time of engine-on signal		Fig. 1.8
Specific impulse		314.9 sec
Thrust	steady-state operation	20,000 ± 200 lbs
Propellant flow rate		63.5 lb/sec
Turnoff step delay $(\Delta T_{\text{tail off}})$		0.540 sec

Turn off transient to (1%)	1.0 sec
Tail off impulse to 10% rated thrust	10,800 ± 1200 lb-sec
Thrust decay vs. time of engine-off signal	Fig. 1.8

The information contained in this section is taken from TRW Systems Document #2131-H005-R8-000, "Apollo Mission Data Specification C AS-207/208A", dated 9 June 1966.

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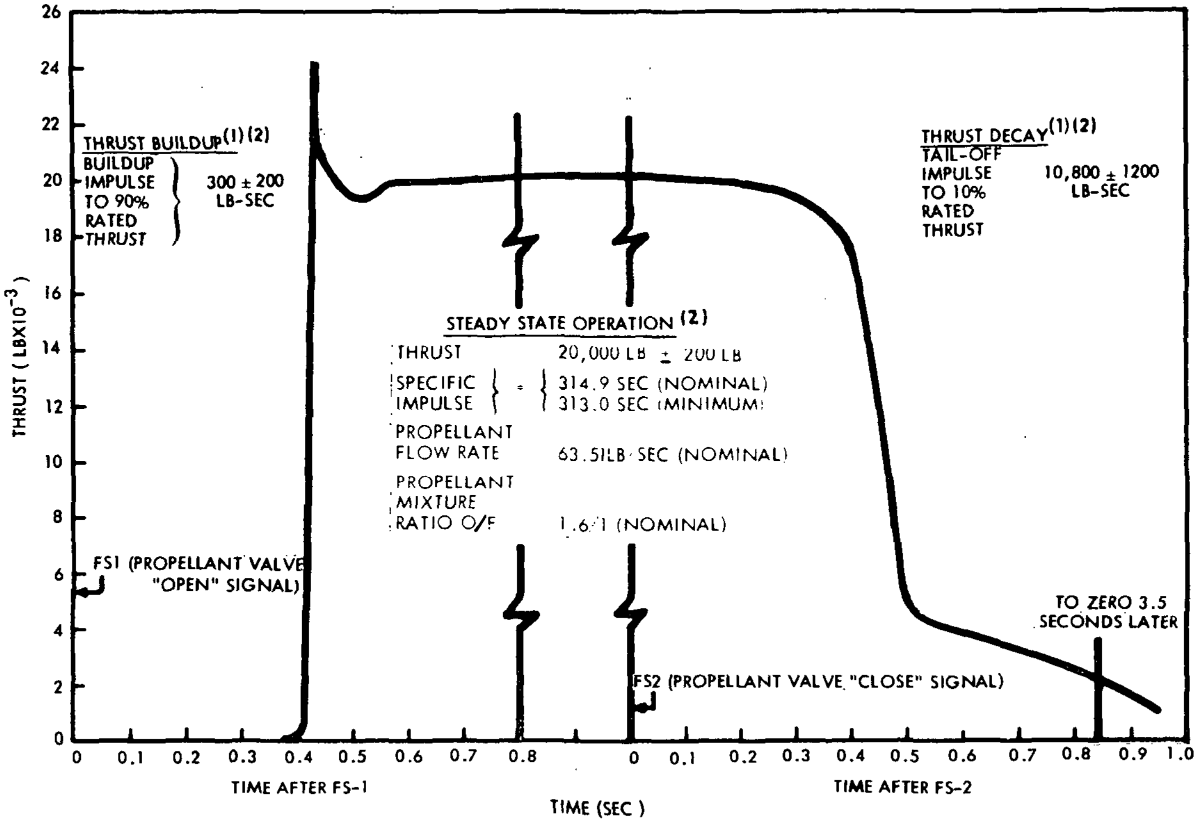


Note : (1) Thrust build up and decay data are based on results of 23 altitude tests of the SPS engine.

(2) High and low values shall be used as 3σ deviations.

Fig. 1.8 SPS Engine Vacuum Performance Summary

1.4.5 CSM Reaction Control System (RCS)

1.4.5.1 RCS Jet Physical Properties

RCS thrust chamber configuration	Fig. 1.9

This figure is taken from TRW Systems Document #2131-H005-R8-000, "Apollo Mission Data Specification C AS207/208A" dated 9 June 1966.

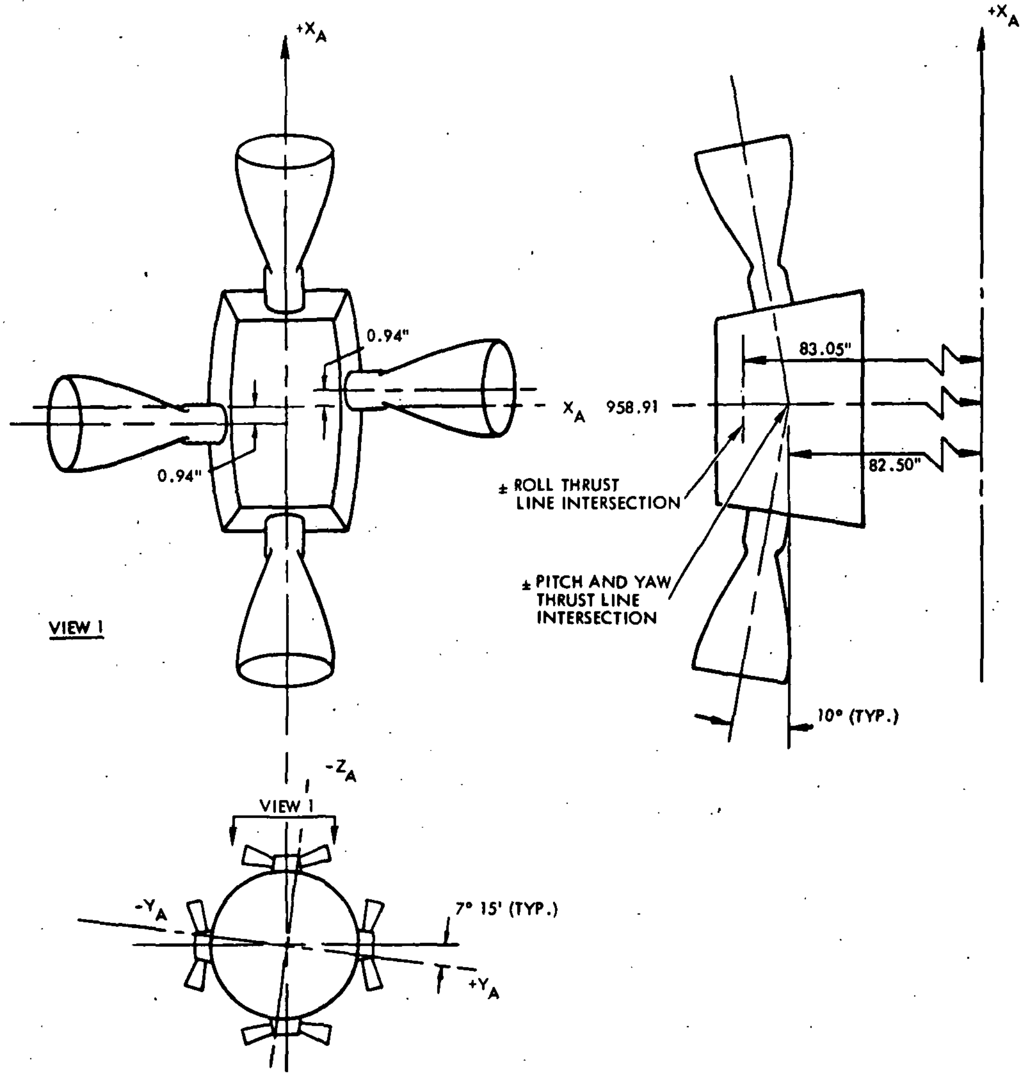
Offset angle	7.25 degrees
Cant angle	10 degrees
Thruster radial arm	83.5596 inches

The above data are taken from the GN&C Data Exchange Program, NAA-S-22 submitted 7 April 1965.

1.4.5.2 RCS Jet Vacuum Performance

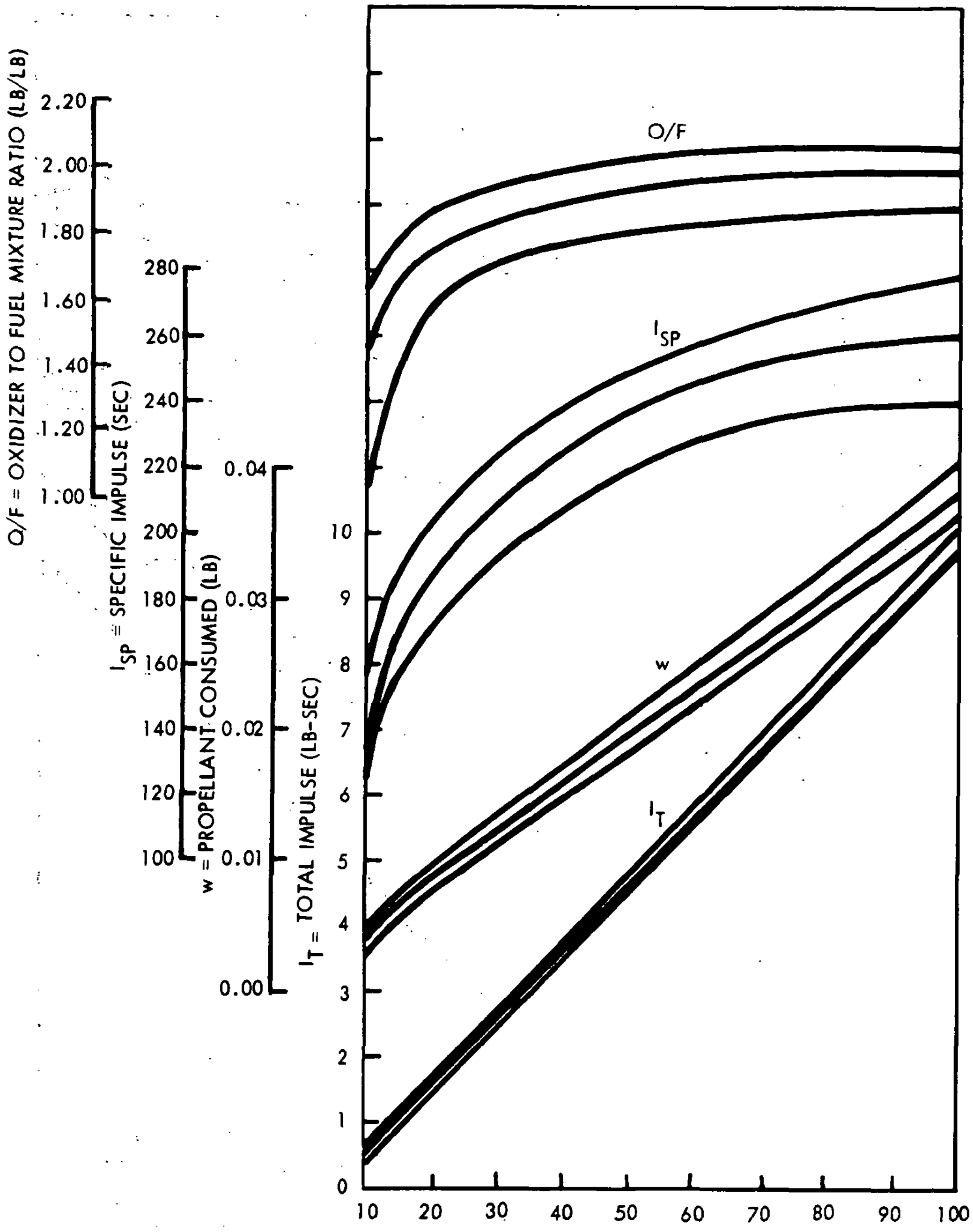
Turn on step delay		0.015 sec
Minimum pulse duration		0.014 sec
Fuel loss per pulse		.0033 lb
Total impulse Specific impulse Propellant consumed	vs. electrical pulse width	Fig. 1.10, 1.11
Steady-state vacuum performance table		Fig. 1.11
Turn off step delay		.0105 sec

The figures referenced in this section are taken from TRW Systems Document #2131-H005-R8-000, "Apollo Mission Data Specification C AS207/208A", dated 9 June 1966.



LOCATION OF SM/RCS CLUSTERS
LOOKING FORWARD INTO SM
(IN THE DIRECTION OF THE $+X_A$ AXIS)

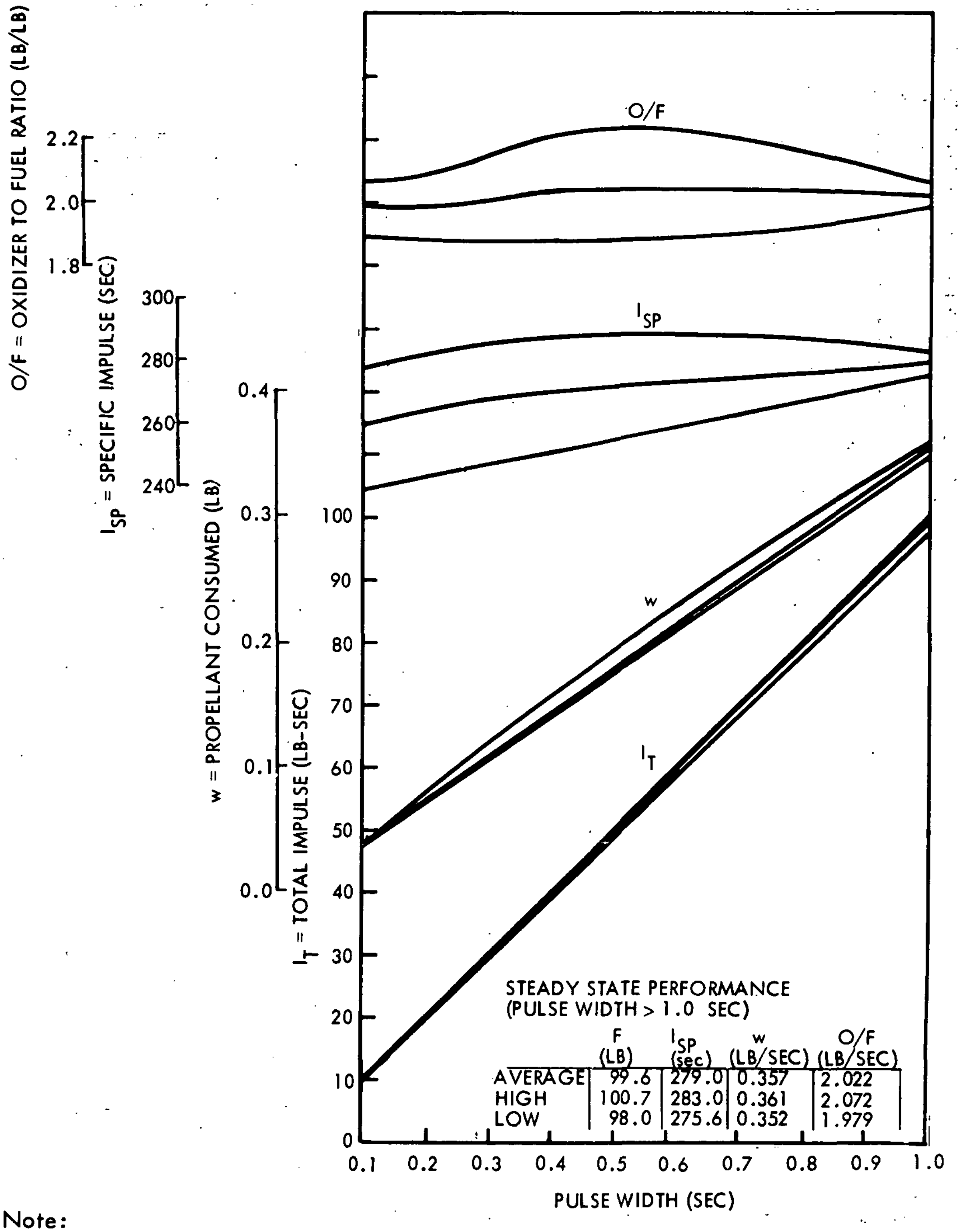
Fig. 1.9 SM/RCS Thrust Chamber Locations



Note:

Data are high, low, and average values resulting from a large number of qualification tests. High and low values shall be used as 3σ values.

Fig. 1.10 SM/RCS Vaccuum Performance Data for Pulse Widths Less than 100 ms



STEADY STATE PERFORMANCE
(PULSE WIDTH > 1.0 SEC)

	F (LB)	I_{SP} (sec)	w (LB/SEC)	O/F (LB/SEC)
AVERAGE	99.6	279.0	0.357	2.022
HIGH	100.7	283.0	0.361	2.072
LOW	98.0	275.6	0.352	1.979

Note:

Data are high, low, and average values resulting from a large number of qualification tests. High and low values shall be used as 3σ values.

Fig. 1.11 SM/RCS Vaccuum Performance Data for Pulse Widths Greater than 100 ms

1.4.6 CM Vehicle Data

1.4.6.1 Apollo CM Coordinate Reference System

Spacecraft CSM-101 reference dimensions	Fig. 1.4
CM axes and notation system	Fig. 1.12

The figures shown in this section are taken from TRW Systems Document #2131-H005-R8-000, "Apollo Mission Data Specification C AS-207/208A" dated 9 June 1966.

1.4.6.2 Specific Station Locations

IMU location X_A = 1056.6 inches

This number is taken from NAA-MIT/IL ICD MH01-01301-116.

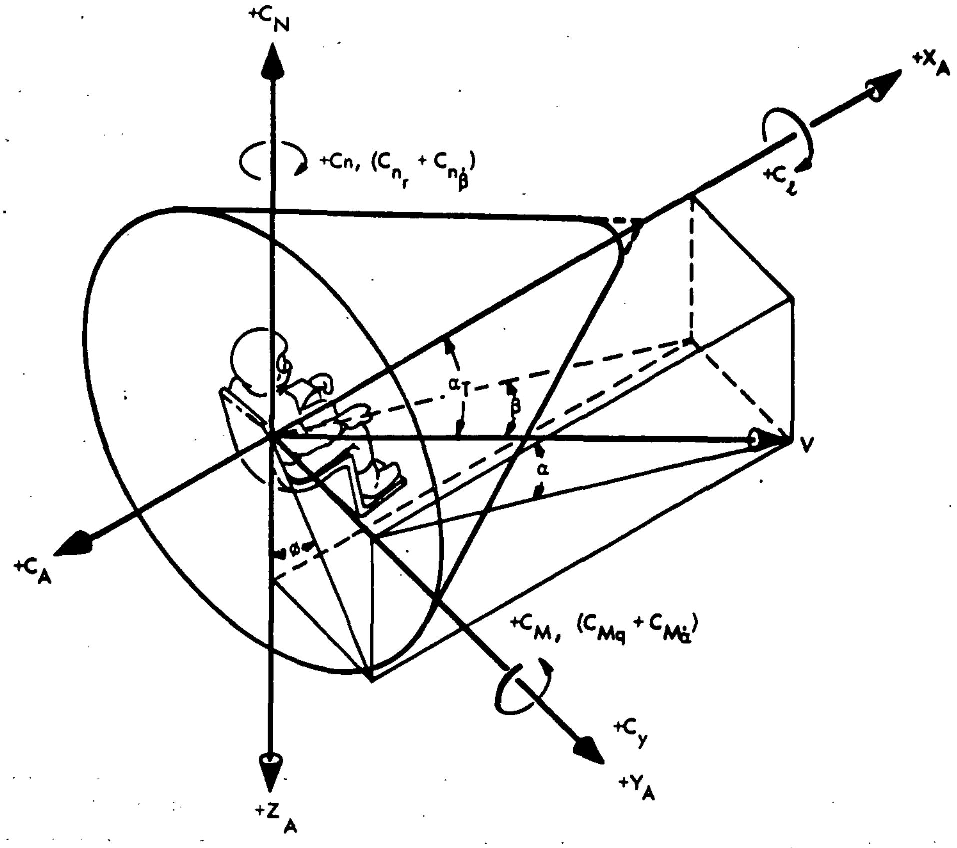
RCS jet thrust locations Table 1.13

This table is taken from TRW Systems Document #2131-H005-R8-000, "Apollo Mission Data Specification C AS-207/208A" dated 9 June 1966.

TABLE 1.13

RCS Jet Thruster Locations

Thrust Chamber	C_L of Thrust Exit Plane on Outer ML				
		X_C	Y_C	Z_C	R_C
5	A	27.6750	72.2846	-4.4211	72.4197
7	B	27.6750	72.2846	4.4211	72.4197
8	C	27.6750	-72.2846	4.4211	72.4197
6	D	27.6750	-72.2846	-4.4211	72.4197
3	E	27.6750	-4.4211	-72.2846	72.4197
1	F	27.6750	4.4211	-72.2846	72.4197
10, 11	(I)G	32,3000	-51.9826	-50.3454	72.3661
9, 12	(II)H	32,3000	51,9826	-50.3454	72.3661
2	J	85.120	3.929	-35.5743	35.7906
4	K	85.120	-3.929	-35.5743	35.7906



$$\cos \alpha_T = \cos \alpha \cos \beta$$

$$\tan \phi = \frac{\tan \beta}{\sin \alpha}$$

C_A	AXIAL FORCE COEFFICIENT (BODY AXIS), AXIAL FORCE/$q_\infty S$
C_ℓ	ROLLING MOMENT COEFFICIENT ABOUT CG (BODY AXIS), ROLLING MOMENT/$q_\infty Sd$
$C_{\ell A}$	ROLLING MOMENT COEFFICIENT ABOUT THEORETICAL CONE APEX (BODY AXIS), ROLLING MOMENT/$q_\infty Sd$
C_M	PITCHING MOMENT COEFFICIENT ABOUT CG, PITCHING MOMENT/$q_\infty Sd$
C_{M_A}	PITCHING MOMENT COEFFICIENT ABOUT THEORETICAL CONE APEX, PITCHING MOMENT/$q_\infty Sd$
C_N	NORMAL FORCE COEFFICIENT (BODY AXIS), NORMAL FORCE/$q_\infty S$
C_n	YAWING MOMENT COEFFICIENT (BODY AXIS), YAWING MOMENT/qSd
C_Y	SIDE FORCE COEFFICIENT (BODY AXIS), SIDE FORCE/qS
$C_{M_q} + C_{M_{\dot{\alpha}}}$	PITCH DAMPING COEFFICIENT , PER RADIAN
$C_{n_r} + C_{n_{\dot{\beta}}}$	YAW DAMPING COEFFICIENT , PER RADIAN
α	ANGLE OF ATTACK, DEGREES
α_T	TOTAL ANGLE OF ATTACK, DEGREES
β	ANGLE OF SIDESLIP, DEGREES
ϕ	ROLL ANGLE, DEGREES
d	REFERENCE LENGTH = 154 INCHES
S	REFERENCE AREA = 129.35 SQUARE FEET
V	FREESTREAM VELOCITY, FEET PER SECOND
q_∞	DYNAMIC PRESSURE, POUNDS PER SQUARE FOOT
q	PITCHING RATE

Figure 1-12 Command Module Axes, Aerodynamic Coefficient, and Notation System

1.4.6.3 Apollo CM Mass Property Data

CM sequential mass properties	Table 1.14
CM-RCS usable propellant summary	Fig. 1.13

The data contained in this section are taken from TRW Systems Document #2131-H005-R8-000, "Apollo Mission Data Specification C AS-207/208A," dated 9 June 1966.

1.4.6.4 CM Vehicle Dynamic Data

Structural bending data (CM/SM coupled)	Table 1.12

The information contained in the table is compiled from the GN&C Data Exchange Program, NAA-S-37 submitted 26 August 1965.

1.4.6.5 Reentry Aerodynamic Data

Reference area		129.35 ft^2
Reference diameter		154.0 inches
Heat shield cant		0.1864 degree
Moment reference center:	X-component	1141.25 inches
	Y-component	0.0 inch
	Z-component	0.0 inch
Aerodynamic coefficients		Table 1.15
Trim aerodynamic coefficients		Table 1.16
Trim L/D vs. c.g. locations		Fig. 1.14

The information contained in this section is taken from TRW Systems Document #2131-H005-R8-000, "Apollo Mission Data Specification C AS-207/208A" dated 9 June 1966.

1.4.6.6 CM RCS Jet Data

RCS thrust chamber configuration	Fig. 1.15
Step delay in RCS thrust application from receipt of command	0.012 second
Minimum pulse duration	0.014 second
RCS jet fuel loss per pulse	0.005 kg
Total impulse Specific impulse Propellant consumed } vs. electrical pulse width	Fig. 1.16, 1.17
Steady state vacuum performance	Fig. 1.17
Step delay in removal of RCS thrust measured from receipt of command	0.007 second

The figures referenced in this section are taken from TRW Systems Document #2131-H005-R8-000, "Apollo Mission Data Specification C AS-207/208A", dated 9 June 1966.

Table 1.14: AS-207A Command Module (CSM-101) Sequential Mass Properties

		Weight (lb)	Center of Gravity[(1)] (in.)			Moments of Inertia[(2)] (slug-ft²)			Products of Inertia[(2)] (slug-ft²)		
			X_A	Y_A	Z_A	I_{xx}	I_{yy}	I_{zz}	I_{xy}	I_{yz}	I_{xz}
CM-Launch, Boost, and Mission		11,510	1,041.9	0.2	5.6	5,597	4,950	4,491	0	-338	17
LESS:	Water	-8	1,022.6	-63.4	-16.4						
	Food	-45	1,049.0	-38.6	25.8						
	Docking	-139	1,110.0	0.0	-2.5						
	EV Visors	-6	1,020.0	38.8	-39.8						
	Thermal-Meteoroid Garment	-21	1,015.0	-24.5	-13.2						
	Constant Wear Garment	-1	1,025.1	7.0	-55.5						
	Emergency Oxygen & Mntg	-9	1,042.7	-25.0	5.0						
	EV Crew Transfer Unit	-6	1,015.0	38.8	-39.8						
	Pre-entry RCS Propellant Consumed	-15	1,022.6	-5.6	57.0						
ADD:	Waste-Fecal	12	1,039.0	47.0	12.0						
	CO_2 Absorbed (17 Cart)	39	1,016.0	-4.2	27.5						
	Potable Water	32	1,022.6	-63.3	-16.4						
	Waste Water	60	1,022.5	-21.0	61.8						
#? – CM-Prior to Entry[(3)]		11,403 ± 520	1,040.9 ± 1.0	0.2 ± 0.5	6.0 ± 0.5	5,628	4,835	4,361	14	-341	20
LESS:	RCS Propellant Consumed	-81	1,022.6	-5.6	57.0						
	Ablator Burnoff (4)	-249	1,013.0	0.0	7.4						
	Entry Coolant	-6	1,022.6	-63.4	-16.4						
	Forward Heat Shield	-300	1,090.0	0.0	1.0						
	Drogue Chutes & Discon.	-63	1,090.3	0.0	-20.9						
CM-Prior to Main Chute Deployment		10,704	1,040.0	0.3	5.9	5,507	4,506	4,082	12	-289	23
LESS:	RCS Propellant Jettisoned	-174	1,022.4	-5.6	57.0						
	Main Chutes	-422	1,090.4	-1.2	7.5						
CM-Post Landing		10,108	1,038.0	0.4	4.9	5,355	4,135	3,794	15	-267	35

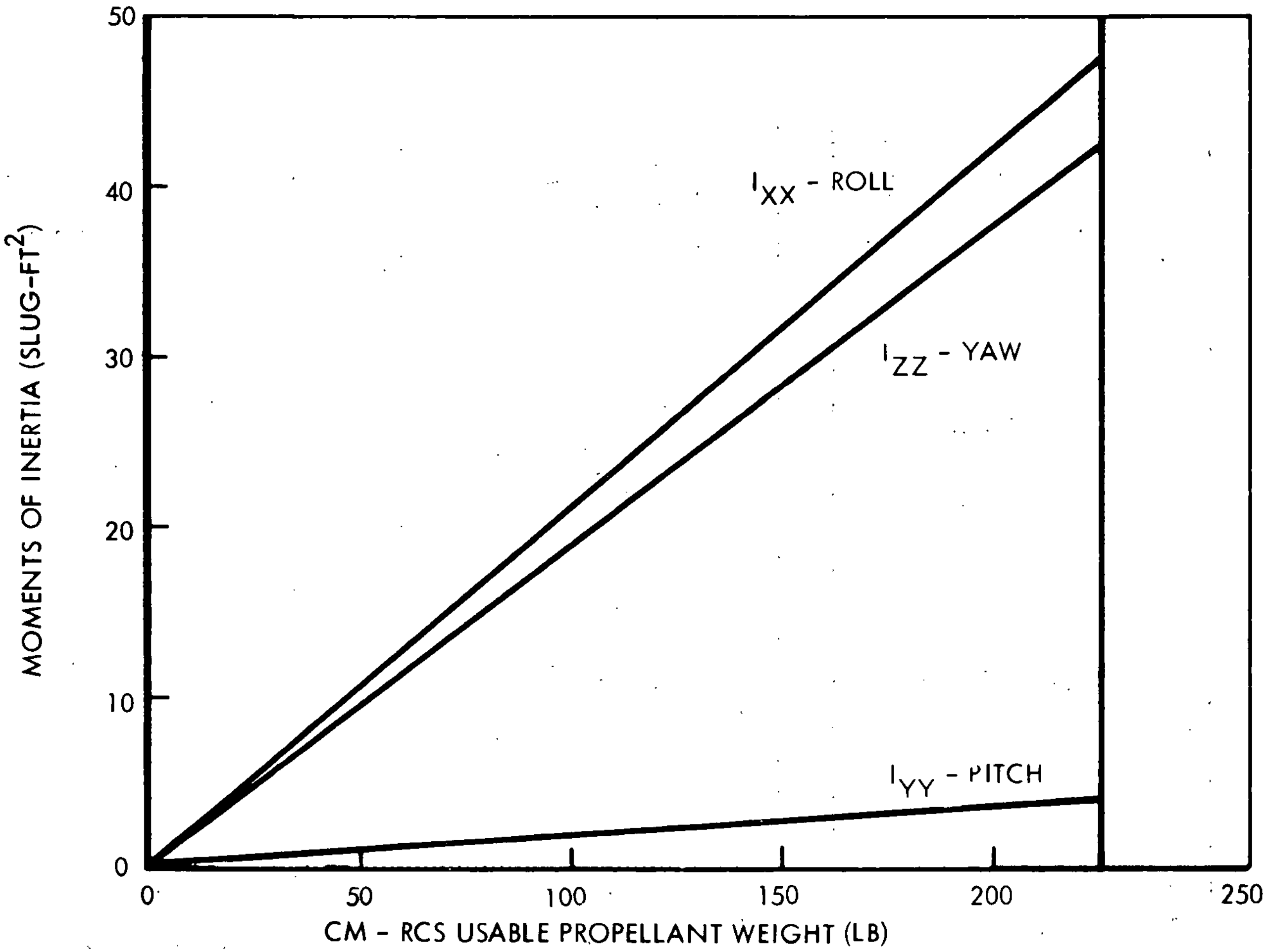
Notes:
(1) Centers of gravity are referenced to the Apollo spacecraft coordinate system origin.

(2) Moments and products of inertia are about the center of gravity of each item.

(3) Tolerances shall be used as 3σ values.

(4) Ablator burnoff does not change L/D trim. See Section 6.1.

#? -: The numbers actually used in the simulation.



Notes: The propellant center of gravity is presented in Table 1.7 and remains constant.
Moments of inertia are about propellant center of gravity.

Fig. 1.13 CM-RCS Usable Propellant Mass Properties

TABLE 1.15

Command Module (CM-101) Reentry Aerodynamic Coefficients

M = 0 to 0.2

Angle of Attack (deg)	C_{M_A}	C_N	C_A
140. 1864	0. 1206	-0. 0401	-0. 6844
145. 1864	0. 1664	-0. 1016	-0. 7454
150. 1864	0. 1935	-0. 1401	-0. 7914
155. 1864	0. 2068	-0. 1686	-0. 8029
160. 1864	0. 2042	-0. 1873	-0. 8137
165. 1864	0. 1780	-0. 1849	-0. 8536
170. 1864	0. 1669	-0. 1147	-0. 8622
175. 1864	0. 0392	-0. 0384	-0. 8542
180. 1864	0. 0075	-0. 0028	-0. 8500

M = 0.4

Angle of Attack (deg)	C_{M_A}	C_N	C_A
140. 1864	0. 1016	-0. 0060	-0. 7471
145. 1864	0. 1397	-0. 0609	-0. 8145
150. 1864	0. 1644	-0.1028	-0. 8645
155. 1864	0. 1674	-0. 1231	-0. 9085
160. 1864	0. 1264	-0. 1042	-0. 9145
165. 1864	0. 0866	-0. 0722	-0. 9004
170. 1864	0. 0556	-0. 0442	-0. 8946
175. 1864	0. 0293	-0. 0240	-0. 8952
180. 1864	0. 0034	-0. 0029	-0. 9040

M = 0.7

Angle of Attack (deg)	C_{M_A}	C_N	C_A
140. 1864	0. 0833	0. 0266	-0. 8409
145. 1864	0. 0900	0. 0050	-0. 9040
150. 1864	0. 0833	-0. 0028	-0. 9363
155. 1864	0. 0531	0. 0191	-0. 9420
160. 1864	0. 0333	0. 0265	-0. 9556
165. 1864	0. 0177	0. 0297	-0. 9727
170. 1864	0. 0044	0. 0282	-0. 9846
175. 1864	-0. 0029	0. 0217	-0. 9967
180. 1864	0.0029	-0. 0033	-1. 0000

TABLE 1.15 (Cont'd)

Command Module (CM-101) Reentry

M = 0.9

Angle of Attack (deg)	C_{M_A}	C_N	C_A
140. 1864	0. 0253	0. 0919	-0. 9349
145. 1864	0. 0157	0. 0880	-0. 9814
150. 1864	0. 0137	0. 0751	-1. 0161
155. 1864	0. 0104	0. 0641	-1. 0512
160. 1864	0. 0100	0. 0502	-1. 0863
165. 1864	0. 0101	0. 0344	-1. 1080
170. 1864	0. 0143	0. 0133	-1. 1211
175. 1864	0. 0146	-0. 0033	-1. 1283
180. 1864	0. 0040	-0. 0037	-1. 1300

M = 1.1

Angle of Attack (deg)	C_{M_A}	C_N	C_A
140. 1864	-0. 0127	0. 1442	-1. 1569
145. 1864	0. 0109	0. 0934	-1. 2115
150.1864	0. 0124	0. 0716	-1. 2372
155. 1864	0. 0061	0. 0664	-1. 2660
160. 1864	0. 0032	0. 0568	-1. 2816
165. 1864	0. 0069	0. 0372	-1. 2945
170. 1864	0. 0072	0. 0218	-1. 2993
175. 1864	0. 0048	0. 0101	-1. 2997
180. 1864	0. 0044	- 0. 0042	-1. 3050

M = 1.2

Angle of Attack (deg)	C_{M_A}	C_N	C_A
140. 1864	-0. 0400	0. 1775	-1. 1734
145. 1864	-0. 0125	0. 1218	-1. 2454
150. 1864	-0. 0043	0. 0936	-1. 2856
155. 1864	0. 0023	0. 0709	-1. 3113
160. 1864	0. 0065	0. 0503	-1. 3286
165. 1864	0. 0143	0. 0235	-1. 3364
170. 1864	0. 0182	0. 0035	-1. 3400
175. 1864	0. 0211	- 0. 0145	-1. 3409
180. 1864	0. 0046	- 0. 0044	-1. 3400

TABLE 1.15 (Cont'd)

Command Module (CM-101) Reentry Aerodynamic Coefficients

M = 1.35

Angel of Attack (deg)	C_{M_A}	C_N	C_A
140.1864	-0.0765	0.2274	-1.2099
145.1864	-0.0407	0.1637	-1.3039
150.1864	-0.0030	0.0960	-1.3684
155.1864	0.0009	0.0742	-1.3924
160.1864	0.0036	0.0553	-1.4044
165.1864	0.0071	0.0358	-1.4066
170.1864	0.0136	0.0114	-1.4036
175.1864	0.0122	-0.0019	-1.3961
180.1864	0.0045	-0.0045	-1.3940

M = 1.65

Angle of Attack (deg)	C_{M_A}	C_N	C_A
140.1864	-0.0829	0.2264	-1.1587
145.1864	-0.0530	0.1779	-1.2770
150.1864	-0.0218	0.1219	-1.3593
155.1864	0.0001	0.0741	-1.3946
160.1864	0.0099	0.0438	-1.4107
165.1864	0.0157	0.0206	-1.4272
170.1864	0.0134	0.0105	-1.4393
175.1864	0.0071	0.0056	-1.4366
180.1864	0.0051	-0.0047	-1.4450

M = 2.0

Angle of Attack (deg)	C_{M_A}	C_N	C_A
140.1864	-0.0728	0.2085	-1.1060
145.1864	-0.0549	0.1764	-1.2293
150.1864	-0.0336	0.1370	-1.3253
155.1864	-0.0089	0.0887	-1.4022
160.1864	0.0058	0.0520	-1.4364
165.1864	0.0099	0.0306	-1.4535
170.1864	0.0155	0.0092	-1.4669
175.1864	0.0155	-0.0066	-1.4707
180.1864	0.0048	-0.0048	-1.4720

TABLE 1.15: (Cont'd)

Command Module (CM-101) Reentry Aerodynamic Coefficients

M = 2.4

Angle of Attack (deg)	C_{M_A}	C_N	C_A
140.1864	-0.0663	0.1989	-1.0710
145.1864	-0.0481	0.1647	-1.1827
150.1864	-0.0262	0.1237	-1.2718
155.1864	-0.0106	0.0902	-1.3508
160.1864	0.0030	0.0567	-1.4113
165.1864	0.0070	0.0372	-1.4548
170.1864	-0.0006	0.0317	-1.4742
175.1864	0.0068	0.0065	-1.4837
180.1864	0.0048	-0.0048	-1.4800

M = 3.0

Angle of Attack (deg)	C_{M_A}	C_N	C_A
140.1864	-0.0497	0.1762	-1.0391
145.1864	-0.0296	0.1396	-1.1466
150.1864	-0.0099	0.1010	-1.2422
155.1864	-0.0000	0.0741	-1.3087
160.1864	0.0069	0.0516	-1.3675
165.1864	0.0109	0.0304	-1.4173
170.1864	0.0037	0.0246	-1.4389
175.1864	0.0106	-0.0006	-1.4592
180.1864	0.0050	-0.0048	-1.4680

TABLE 1.15 (Cont'd)

Command Module (CM-101) Reentry Aerodynamic Coefficients

M = 6 to 25

Angle of Attack (deg)	C_{M_A}	C_N	C_A
110. 1864	-0. 2200	0. 3730	-0. 1820
115. 1864	-0. 1745	0. 3340	-0. 3350
120. 1864	-0. 1340	0. 2960	-0. 4700
125. 1864	-0. 1025	0. 2590	-0. 6050
130. 1864	-0. 0770	0. 2260	-0. 7300
135. 1864	-0. 0570	0. 1960	-0. 8550
140. 1864	-0. 0401	0. 1681	-0. 9795
145. 1864	-0. 0280	0. 1417	-1. 0830
150. 1864	-0. 0183	0. 1188	-1. 1767
155. 1864	-0. 0105	0. 0946	-1. 2673
160. 1864	-0. 0046	0. 0731	-1. 3448
165. 1864	-0. 0004	0. 0512	-1. 4140
170. 1864	0. 0021	0. 0294	-1. 4614
175. 1864	0. 0040	0. 0105	-1. 4843
180. 1864	0. 0050	-0. 0048	-1. 4900
185. 1864	0. 0040	-0. 0100	-1. 4780
190. 1864	0. 0025	-0. 0125	-1. 4500

TABLE 1.16

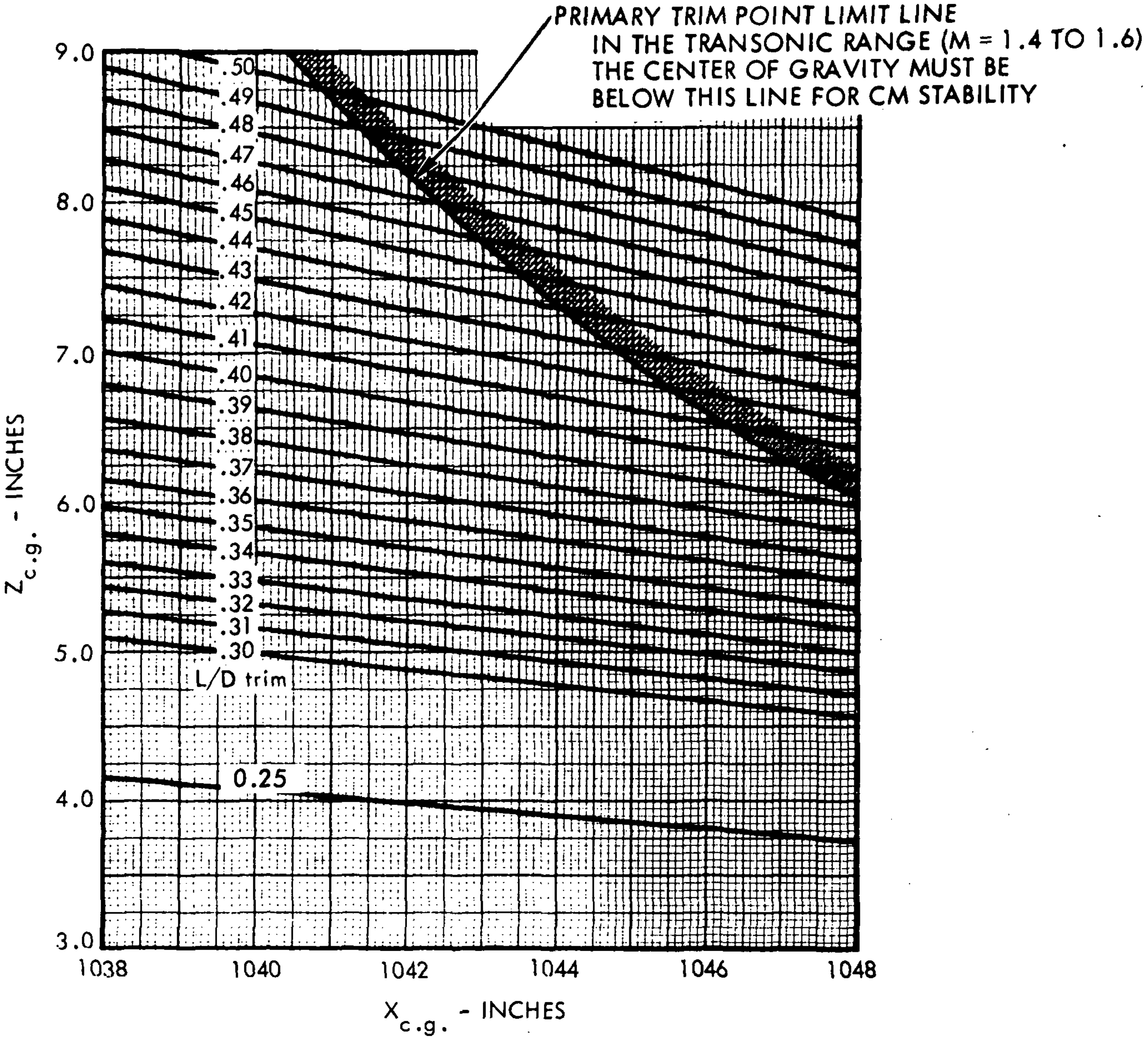
Command Module (CM-101)

Reentry Trim Aerodynamic Coefficients(1)

M	TRIM (deg)	$C_{L_{TRIM}}$	$C_{D_{TRIM}}$	L/D_{TRIM}
0.20	174.42	+0.1310	+0.8467	+0.1547
0.40	166.72	+0.2674	+0.8590	+0.3112
0.70	164.87	+0.2251	+0.9458	+0.2380
0.90	160.35	+0.3188	+1.0407	+0.3063
1.10	155.19	+0.4709	+1.1771	+0.4001
1.20	153.61	+0.5100	+1.2028	+0.4240
1.35	153.07	+0.5561	+1.2715	+0.4373
1.65	152.50	+0.5507	+1.2694	+0.4338
2.00	152.34	+0.5294	+1.2606	+0.4200
2.24	152.85	+0.5066	+1.2187	+0.4157
3.00	153.90	+0.4971	+1.1966	+0.4154
6.25	155.96	+0.4383	+1.2062	+0.3634

(1) Data derived from Table 6-3, based on the nominal center of gravity of the "CM-prior to Entry."

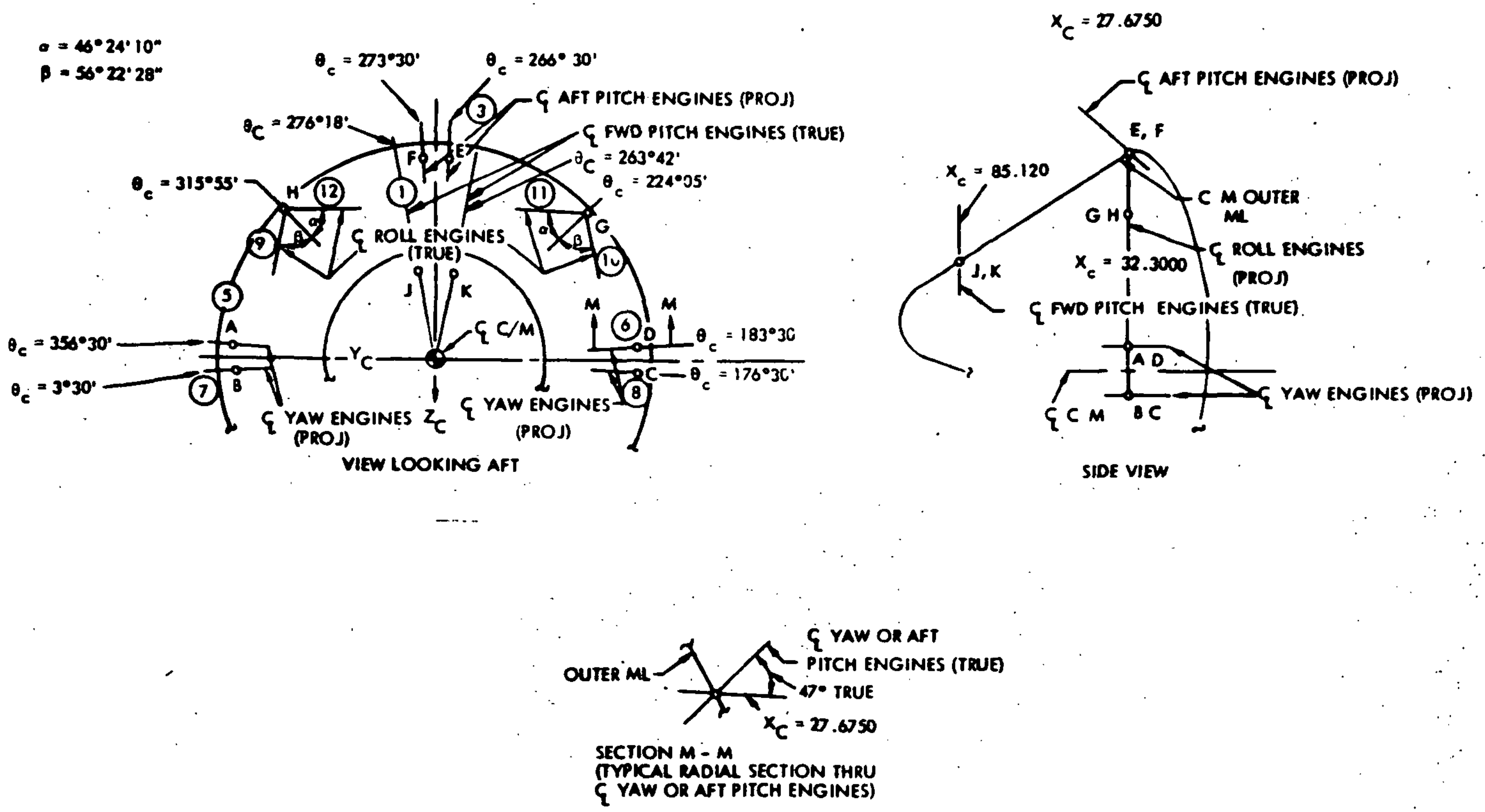
This center of gravity location is based on an estimate of RCS propellant consumption prior to entry. After completion of detailed entry trajectories, this estimate may not be valid. In addition, RCS propellant is consumed during entry, which is not accounted for in these trim aerodynamic coefficients. Therefore, these data are to be used only for simplified entry studies.



NOTE: BASED ON NOMINAL DATA IN TABLE 1.15. FOR MACH NUMBERS OF 6 TO 25.

Data are applicable for the CM without ablation.

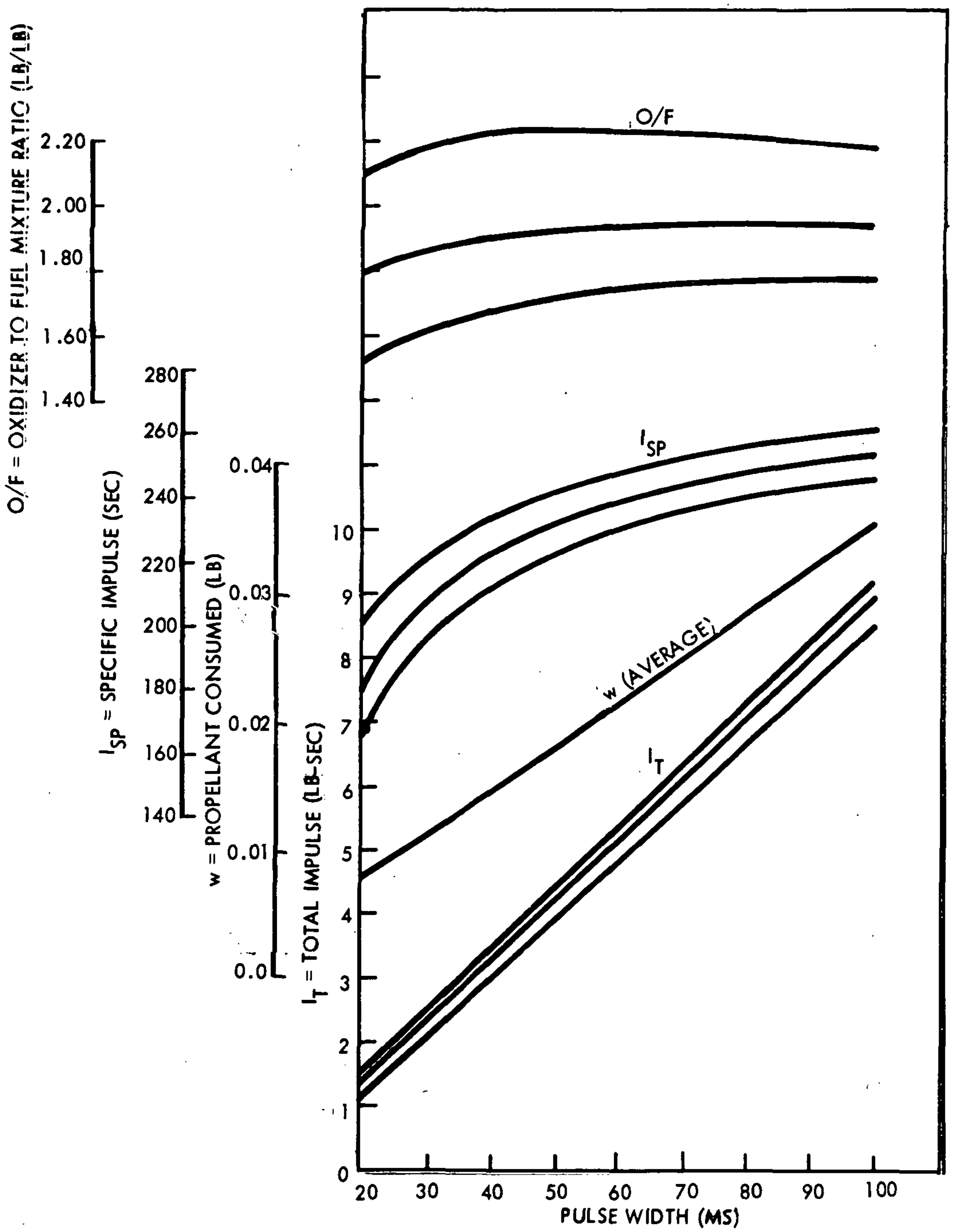
Figure 1.14 Command Module Without Protuberances (CM-101) Trim Lift to Drag Ratio Versus c. g. Location



Notes: (1) Not on outer ML - intersection point of roll engine centerline.

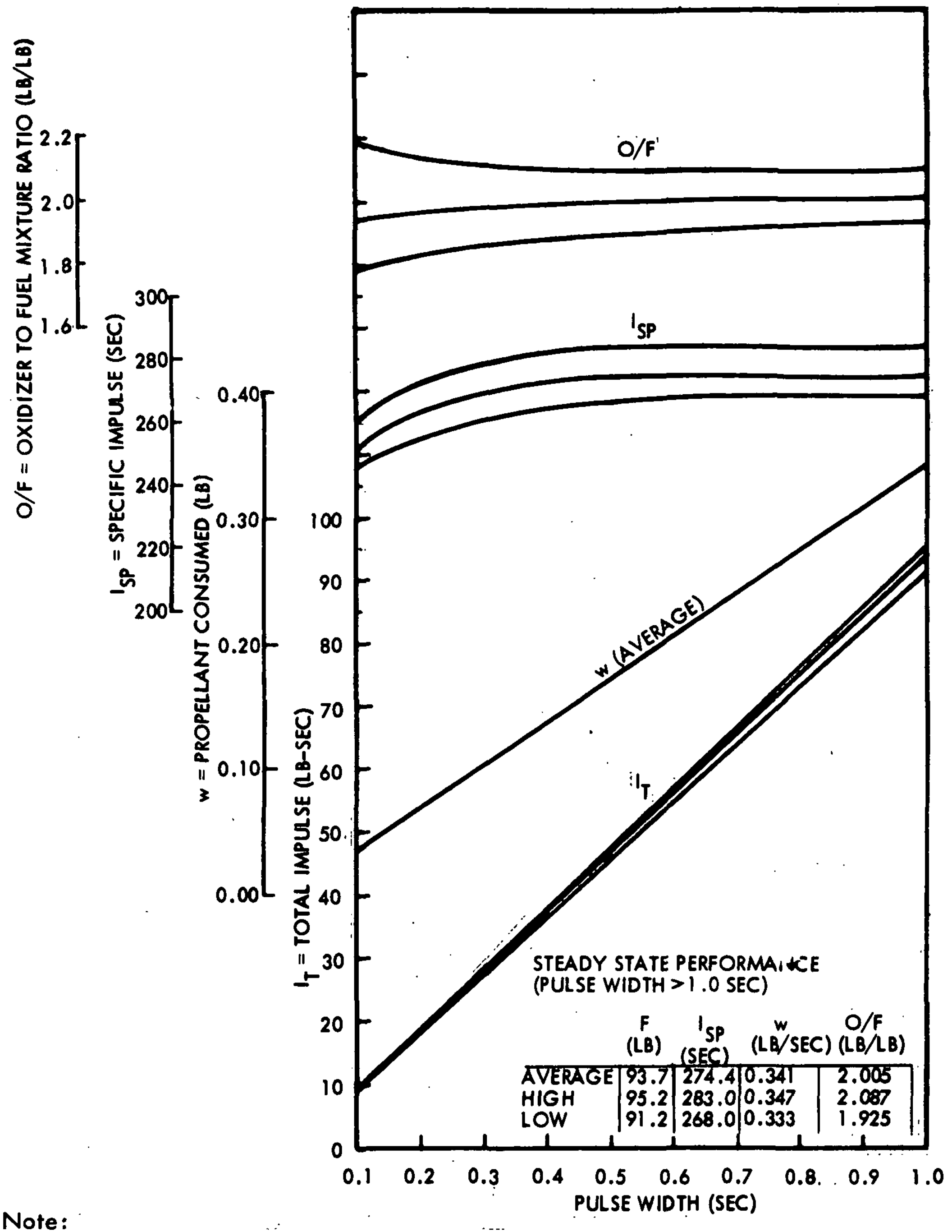
(2) All linear measurements in inches.

Figure 1.15 CM/RCS Thrust Chamber Locations



NOTE: Data are high, low and average values resulting from a large number of qualification tests, with the exceptions of w, where only average values are available. High and low values shall be used as 3 σ values.

Fig. 1.16 CM/RCS Vacuum Performance Data for Pulse Width Less than 100 ms



STEADY STATE PERFORMANCE
(PULSE WIDTH >1.0 SEC)

	F (LB)	I_{SP} (SEC)	w (LB/SEC)	O/F (LB/LB)
AVERAGE	93.7	274.4	0.341	2.005
HIGH	95.2	283.0	0.347	2.087
LOW	91.2	268.0	0.333	1.925

Note:

Data are high, low and average values resulting from a large number of qualification tests, with the exception of w, where only average values are available. However, high and low values of w are presented for steady state operation. High and low values shall be used as 3σ values.

Fig. 1.17 SM/RCS Vaccuum Performance Data for Pulse Widths Greater than 100 ms

1.5 Physical Constants

The following three docume[redacted]ce for this whole section:

1) NASA SP-7012, "The International System of Units - Physical Constants and Conversion Factors, "MSFC 1964.

2) NASA M-DE-8020-008B, "Natural Environment and Physical Standards for the Apollo Program", April 1965.

3) NASA Working Paper 10, 020B, "Directory of Standard Geodetic and Geophysical Constants for Gemini and Apollo", 6 April 1966.

1.5.1 Geophysical Parameters

Parameters	Symbol	Value
Equatorial earth radius (gravitational)	R_e	$0.63781\ 65 \times 10^{7}$ meters
Acceleration of gravity (standard	g_o	$0.98066\ 50000 \times 10^{1}\ \frac{\text{meters}}{\text{sec}^2}$
Gravitation parameter	μ_e	$0.39860\ 32 \times 10^{15}\ \frac{\text{meter}^3}{\text{sec}^2}$
Mass of the earth	M_e	0.5975×10^{25} kilogram
Rotational rate of the earth (1966-72)	ω_e	$0.72921\ 1506 \times 10^{-4}\ \frac{\text{radian}}{\text{second}}$

Gravitational potential harmonic coefficients:

second-order term	J	$0.16234\ 5 \times 10^{-2}$
third-order term	H	-0.575×10^{-5}
fourth-order term	D	0.7875×10^{-5}
	J_{22}	0.19×10^{-5}
	λ_{22}	-21 degrees

1.5.2 General Constants

π	$0.31415\ 92653 \times 10^{1}$

1.5.3 Conversion Factors with 10 Significant Figures

To Convert	Symbol	Multiply By
Feet to Meters	FTM	0.30480 00000
Slugs to Kilograms	STK	$0.14593\ 90293 \times 10^{2}$
Pounds to Kilograms	PTK	0.45359 23700
Degrees to Radians	DTR	$0.17453\ 29251 \times 10^{-1}$
Inches to Meters	ITM	0.02540 00000
Pounds to Newtons	PTN	$0.44482\ 21615 \times 10^{1}$
Foot Pounds to Newton Meters	FPT NM	$0.13558\ 17948 \times 10^{1}$
Nautical Mile to Kilometers		$0.18520\ 00000 \times 10^{1}$
Statute Miles to Kilometers		$0.16093\ 44000 \times 10^{1}$
Slug-Feet^2 to Kilogram-Meter^2		$0.13558\ 17948 \times 10^{1}$

1.5.4 Conversion Factors and Scaling Constants

Conversion Factors and Scaling constants pertaining to the entry mission phase may be found in the Reentry Guidance section of this document.

1.5.5 Reference Models

The Fischer Ellipsoid of 1960 is the accepted mathematic model of the earth. This model is to be used as the surface of reference for all geodetic coordinates.

Equatorial earth radius	a	$0.63781\ 66 \times 10^{7}$ meters
Polar earth radius	b	$0.63567\ 84284 \times 10^{7}$ meters
Flattening $\frac{a-b}{b}$	f	$0.33523\ 29869 \times 10^{-3}$
Eccentricity of ellipsoid	e	$0.81813\ 33402 \times 10^{-3}$

Atmospheric Model for earth orbit and translunar phase

"U.S. Standard Atmosphere of 1962"
U.S. Government Printing Office.

Atmospheric Model for reentry phase

a) *For altitudes above 90 kilometers*
"U.S. Standard Atmosphere of 1962"

b) For altitudes below 90 kilometers
"Air Force Interim Supplemental Atmospheres to 90 km"
Air Force Surveys in Geophysics No. 153

1.6 Carry-On Data

This page is intentionally left blank. Carry-on data are not available at this time. The appropriate landmarks will be selected using the ground track data in the spacecraft reference trajectory.

1.7 Block II GN&C System Description

1.7.1 GN&C Hardware Configuration

System 204 will be GNC system for Mission 278. It is a normal Block II system except for the Signal Conditioning Assembly which processes FLIGHT QUALIFICATION measurements as well as OPERATIONAL measurements. The system is comprised of the following major assemblies:

Inertial Measurement Unit (IMU)
PIPA Electronics Assembly (PEA)
Coupling Data Unit (CDU)
Navigation Base (NB)
Optical Unit (including Space Sextant-SXT and Scanning Telescope - SCT)
Command Module Computer (CMC)
Two (2) Display Keyboard Assemblies (DSKY)
Display and Control Group
Power and Servo Assembly (PSA)
Signal Conditioning Assembly (SCA-FQ)
G&N Interconnect Harness Group
Eyepiece Storage Unit (ESU)

1.7.2 GN&C Spacecraft Signal Interfaces

1.7.2.1 Interface Control Documents (ICD's)

Below are presented the Interface Control Documents (ICD's) which are pertinent to definition and understanding of the electrical/functional interfaces between the GN&C system and the spacecraft, the launch vehicle and the astronauts. Additional existing ICD's pertaining to mechanical interfaces, thermal interfaces, etc. are not listed because they are not considered to be relevant to this document.

General Interfacing Area	ICD Title	ICD No.	Description
Electrical Power	G&N Electrical Input Power	MH-01-01327-216 (IRN 0055)	Total a-c and d-c Power specification from CSM to GNC.
Displays	Attitude Error	MH 01-01324-216 (IRN's 1499, 3605)	Signal interface for following: a) Pitch Error b) Roll Error c) Yaw Error d) 800-cps reference
	Total Attitude Signals	MH 01-01325-216 (IRN's 0823, 3614, 3616)	Signal interface for following 800-cps modulated signals to FDA1 and attitude set resolver: a) Sine AIG b) Cosine AIG c) Sine AMG d) Cosine AMG e) Sine AOG f) Cosine AOG
	G&N Master Warning and Caution Lamps	MH 01-01342-216	Electrical interface from S/C Alarm system to GNC displays
Telemetry	G&N Data Transmission to Operational and Flight Qualification Telemetry	MH 01-01328-216 (Rev. A)	Electrical interface for GNC PCM and Flight Recorder measurements.
Steering	CDU to TVC Servo Amplifiers	MH 01-01307-216 (IRN's 0826, 3604)	Electric (d-c) interface to SPS for: a) Pitch Command b) Yaw Command
	G&N Attitude Signals to Saturn Guidance	MH 01-01386-216	Electrical (d-c) interface to Saturn Guidance for: a) Roll Attitude Error b) Pitch Attitude Error c) Yaw Attitude Error
Moding	Mode Control Signals S/C to ISS Discretes	MH 01-01344-216 (IRN's 3601)	Switch closure discrete to ISS: a) IMU Cage b) GNC A/P Control c) S/C Control of Saturn
CMC	CMC Electrical Interfaces-Block II	MH 01-01380-216 (Rev. A)	Defines the electrical interfaces between CMC and CSM. For details see Sec. 1.7.2.2.

1.7.2.2 CMC/CSM Signal Interface

The following section lists the complete interface between the CMC and CSM as described in detail by ICD MH 01-01380-216 Rev. A. Figure 1. 18, a schematic representation of the interface, will be submitted later.

1.7.2.2.1 CMC/CSM Interface - Inputs to CMC

1)	LM Attached	Control Mode and Status
2)	SPS Ready	
3)	Attitude Hold	
4)	Free Drift	
5)	Accept Uplink	
6)	CM/SM Separate	
7)	SIVB Separate	
8)	Liftoff	
9)	Guidance Reference Release	
10)	Ullage Thrust Present	
11)	Plus Roll	Pulses attitude increments from Gyro Display Coupler
12)	Minus Roll	
13)	Plus Pitch	
14)	Minus Pitch	
15)	Plus Yaw	
16)	Minus Yaw	
17)	Plus Roll	Command Discretes from Rotational Hand Controller
18)	Minus Roll	
19)	Plus Pitch	
20)	Minus Pitch	
21)	Plus Yaw	
22)	Minus Yaw	
23)	Plus X	Command Discretes from Translational Hand Controller
24)	Minus X	
25)	Plus Y	
26)	Minus Y	
27)	Plus Z	
28)	Minus Z	
29)	Start	PCM Downlink
30)	Stop	
31)	Bit Sync	
32)	Uplink "One"	Uplink
33)	Uplink "Zero"	

1.7.2.2.2 CMC/CSM Interface - Outputs from CMC

1)	+ Pitch/+X	SCS Reaction Control System Jet-Firing Commands
2)	- Pitch/+X	
3)	+ Pitch/-X	
4)	- Pitch/-X	
5)	+ Yaw/+X	
6)	- Yaw/+X	
7)	+ Yaw/-X	
8)	- Yaw/-X	
9)	+ Roll/+Z	
10)	- Roll/+Z	
11)	+ Roll/-Z	
12)	- Roll/-Z	
13)	+ Roll/+Y	
14)	- Roll/+Y	
15)	+ Roll/-Y	
16)	- Roll/-Y	
17)	SPS Firing Command	To SPS
18)	SIVB Fire Cycle	To Saturn Engine
19)	SIVB Engine Cutoff	
20)	Master Clock (1024K)	Central Timing Equipment
21)	Digital Downlink Data	PCM
22)	CMC Warning	Caution & Warning Subsystem
23)	ISS Warning	
24)	PGNC Caution	

2. MISSION AND VEHICLE SIMULATION DATA

2.1 Scope

Section 2 is an attempt to summarize all data that are presently being used for flight simulations and rope verification of LGC programs.

Numerical values are recorded in the most widely accepted units and may not be found in the memory explicitly as defined. These values are often re-scaled, units corrected, or combined with other data in the most convenient and/or economical fashion.

Apollo mission and vehicle data for flight AS-208A, LM-2 have been collected under the following headings:

> Apollo Mission Data (Section 2.2) establishes the outlines of the mission in terms of trajectories, attitude histories, etc. These data are required for environment simulation and LGC program verification.
>
> LGC Memory Data (Section 2.3) contains mission and vehicle dependent data that are written directly into the memory of the LGC. Other memory data are referred to in Volume II Sections 3,4, and 5. The limited erasable section is reserved primarily for storage of computational variables. Those parameters that do not change during flight have been assigned to the fixed section of the memory.
>
> Apollo Spacecraft LM-2 Data (Section 2.4) is a compilation of vehicle characteristics information and mathematic model descriptions which are being used with the mission data for an effective flight simulation. Vehicle configuration, mass properties, dynamic structural data, and engine performance data are included. This information will not generally appear directly in the LGC program.
>
> Constants and Conversion Factors (Section 2.5) will be used directly in LGC programs as well as simulations. The LGC is programmed in the metric set of kilogram, meter, and centisecond (10^{-2} second). Conversion to these units is accomplished by use of the factors defined in this section. Applicable geodetic and geophysical data are included.
>
> Carry-On Data (Section 2.6) contains miscellaneous charts and notes hand-carried by the astronauts.
>
> LM PGNC System Configuration (Section 2.7) defines the provisions incorporated in the PGNC System to mechanize the required system operation. A listing is included of the Interface Control Documents (ICD's) which are pertinent to an understanding and definition of the functional interfaces between the PGNCS and the S/C and the astronaut.

2.2 Apollo Mission Data

2.2.1 Mission Trajectory

This section will use the following data source: TRW Systems Document #05952-H041-R8-000, "Apollo Mission AS-207/208A Spacecraft Reference Trajectory" dated 7 October 1966.

2.2.2 Nominal LM/SIVB Docking Attitude Conditions

X_{LM}-axis is in the plane of the trajectory, in the direction of the forward horizontal

Y_{LM}-axis along the momentum vector $\underline{\underline{R}} \times \underline{V}$

Z_{LM}-axis points up and parallel to the geocentric radius vector

Roll rate	0 degree/second
Pitch rate	0 degree/second
Yaw rate	0 degree/second

2.2.3 Dispersions (3-sigma) for Nominal Attitude Conditions at Docking

X_{LM}-axis attitude	2 degrees
Y_{LM}-axis attitude	2 degrees
Z_{LM}-axis attitude	2 degrees
Roll rate residual	0.2 degree/second
Pitch rate residual	0.2 degree/second
Yaw rate residual	0.2 degree/second

2.2.4 LM/CSM Docked Orientations

LM/CSM reference dimensions docked orientation	Fig. 1.1

The referenced figure is taken from TRW Systems Document #2131-H005-R8-000, "Apollo Mission Data Specification C AS-207/208A," dated 9 June 1966.

2.2.5 SIVB Attitude Maneuver Requirements

Summary of SIVB orbital attitude maneuvers	Table 2.1

This table is taken from United States Government Memorandum #66-FM13-238 dated 19 July 1966.

Table 2.1 Summary of SIVB Orbital Attitude Maneuvers Prior To and After SIVB/Spacecraft Separation for Mission AS-208

Maneuver Description	Approximate Timing of Maneuver	Maneuver Mode	Maneuver Rate	Purpose
Establish zero degree attitude between the SC X-axis and the local horizontal with the LM forward	Start immediately after orbital insertion	SIVB Computer	0.5	
		Provide ground command over-ride		
Maintain SC X-axis alignment with the local horizontal with the LM forward	Start immediately after previous maneuver	SIVB Computer	Average orbit rate	To provide visibility of acquisition light
Pitch 180 deg, roll 180 deg with respect to the local horizontal	Between 2-1/2 - 3 hours after orbit insertion for an on-time launch	Ground command initiation of an IU preprogrammed maneuver	1.0	To obtain lighting conditions for station keeping and heads-up attitude
	Between 4 - 4-1/2 hours after orbit insertion for a late launch			
Maintain SC X-axis alignment with the local horizontal with the LM backward	Start immediately after the previous maneuver	SIVB Computer	Average orbit rate	To maintain proper lighting conditions for station keeping
Establish a selected inertial attitude depending on lighting and communications requirements for docking	Between 3 - 3-1/2 hours after orbit insertion for an on-time launch	Ground command initiation of an SIVB Computer preprogrammed maneuver	0.5	To provide lighting conditions for docking
	Between 4-1/2 - 5 hours after orbit insertion for a late launch			
Maintain inertial docking attitude with ± 1 degree deadband	Start immediately after previous maneuver	SIVB Computer	Inertially stablized limit cycle	Docking and LM withdrawal
Establish the SIVB roll axis aligned with the local horizontal in retrograde attitude	Start after LM extraction is completed at approximately 4 hours after insertion	Initiate post-separation sequence by single ground command	0.5	
Maintain retrograde attitude for system lifetime	Start after completion of the previous maneuver	SIVB Computer	Average orbit rate	Force SIVB venting to be in retrograde direction

2.3 LGC Memory Data

2.3.1 Prelaunch, Launch Pad #37B

	Memory	Value
Geodetic latitude	E	28.53185664°N
Longitude	E	279.43504723°E
Geocentric radius	E	6373319.36 meters
Geocentric radius to GN&C	-	6373376.26 meters
Fischer ellipsoid radius	E	6373319.36 meters
Geoidal separation (height of MSL above ellipsoid)	-	0.0 meters
Altitude of launch pad above MSL	-	0.0 meters
Inertial reference plane azimuth	E	117°E of True North

The information in this section is taken from NASA General Working Paper 10,020B "Directory of Geodetic and Geophysical Constants For Gemini and Apollo," dated 6 April 1966.

2.3.2 Attitude Maneuver Memory Data

Attitude maneuver constants will be found in Vol. II LM Digital Auto Pilot (DAP) section of this document. Later issue will indicate fixed or erasable location.

2.3.3 TVC Memory Data

Refer to DAP section. Later issue will indicate fixed or erasable location.

2.3.4 Vehicle Memory Data

Refer to DAP section. Later issue will indicate fixed or erasable location.

2.3.5 Programmed Time Delays

The preset delays between events are outlined in Vol. II Section 4. Some of these delays are in fixed memory and some in erasable memory. (Erasable memory delays are underlined)

2.3.6 Guidance, Navigation, and Control Constants

The constants used in the guidance, navigation, and control equations are presented in Vol. II Section 5. These constants are in the fixed portion of the memory.

2.3.7 Navigational Star Memory Data

Star list Table 1.2

The X and Z component for each star appear directly in the LGC fixed memory. The Y-component of the coordinate system is such as to make $X^2 + Y^2 + Z^2 = 1$, where X, Y, and Z are the components of a unit vector pointing from the center of the sun to the star, as of the first of the Besselian year occurring nearest to the launch date. The Z-axis of the coordinate system is in the direction of the mean axis of rotation of the earth. The X-axis is in the direction of the First of Aries at the beginning of the above-defined Besselian year.

Table 1.2 star locations are not corrected for light aberration due to apparent motion. Please note that these locations are only valid for launch dates before 30 June 1967. Should the launch schedule slip, new star locations would have to be determined based upon the first of the following Besselian year.

2.4 Apollo Spacecraft LM-2 Data

2.4.1 Apollo Vehicle Coordinate Reference System

LM reference dimensions	Figure 2.1

The referenced figure is taken from TRW Systems Document #2131-H005-R8-000, "Apollo Mission Data Specification C AS-207/208A," dated 9 June 1966.

2.4.1.1 Specific Station Locations

	X_E	Y_E	Z_E	Units
Descent engine position	3.9116	0	0	meters
Ascent engine position	5.9436	0	0	meters

The above data are taken from GAEC Internal Memo, LMO-500-323 dated 30 August 1965.

Navigation base position	7.7978	0	1.27	meters

The source of the above data is unknown.

RCS jet thruster locations	Table 2.3

The data in this table are taken from GAEC Internal Memo, LMO-500-323 dated 30 August 1965.

Position of descent fuel and oxidizer tanks	Table 2.4
Position of ascent fuel and oxidizer tanks	Table 2.4
Radius of descent tanks	0.646176 meter
Radius of ascent tanks	0.621792 meter

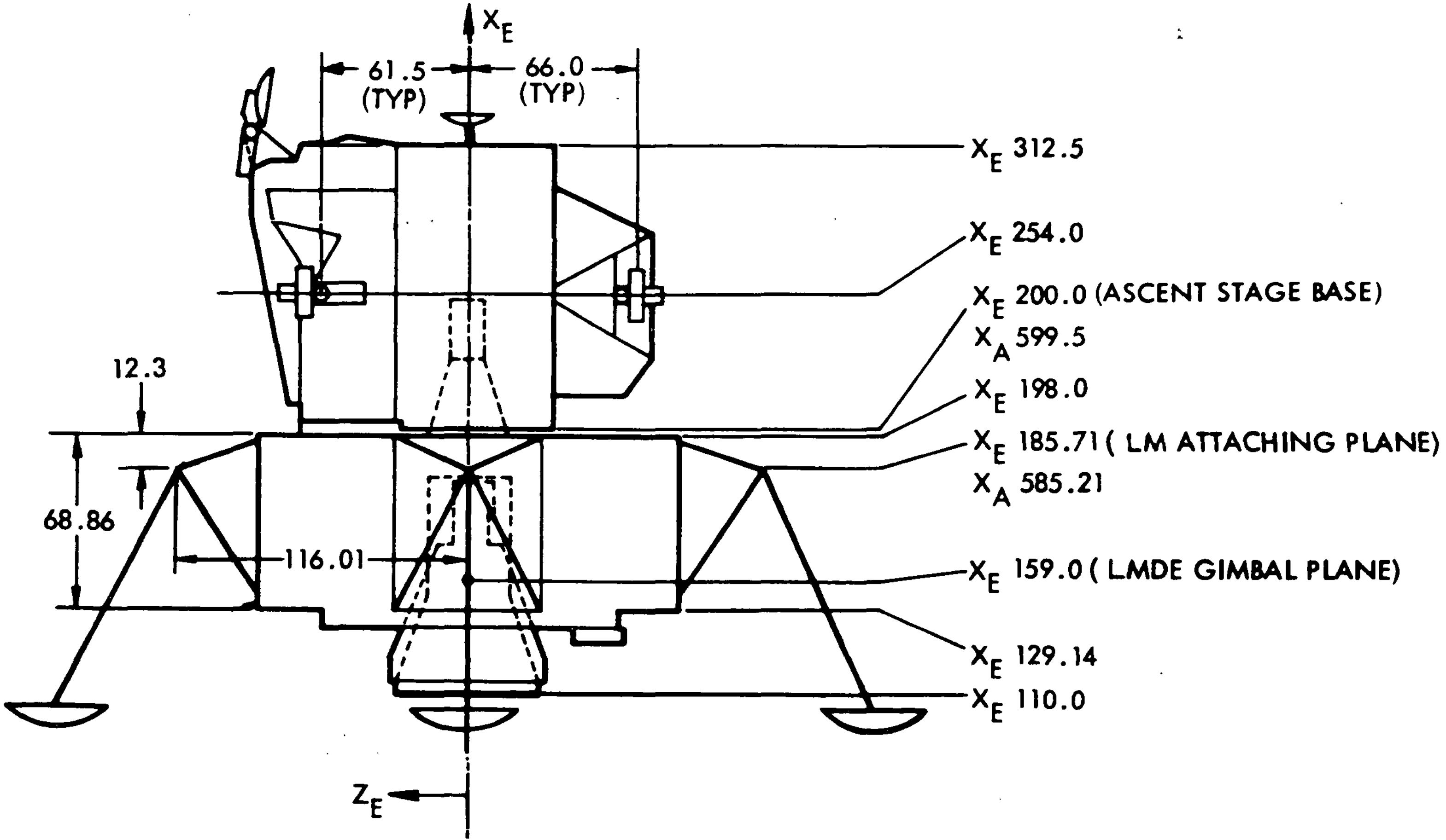
The above data are taken from GAEC Internal Memo, LMO-500-258, dated 5 August 1965.

2.4.2 Apollo Vehicle Mass Properties Data

LM vehicle mass properties follows at various phases.

<u>Fully-Loaded LM</u>

Mass		14812.0588 Kilograms
C.G.	X-component	4.699 meter
	Y-component	0.02794 meter
	Z-component	0.00254 meter
Moment of Inertia	I_{xx}	31883.41425 N•m sec^2
	I_{xy}, I_{yx}	-195.2377807 N•m sec^2
	I_{xz}, I_{zx}	-573.5109810 N•m sec^2
	I_{yy}	34551.66392 N•m sec^2
	I_{yz}, I_{zy}	-625.032062 N•m sec^2
	I_{zz}	34570.64537 N•m sec^2



NOTE: X_E = LM COORDINATE SYSTEM

X_A = APOLLO SPACECRAFT COORDINATE SYSTEM

ALL LINEAR DIMENSIONS ARE IN INCHES

RCS PITCH AND ROLL JETS Z_E AND Y_E = ±66.1 (EFFECTIVE GEOMETRIC MOMENT ARM)

RCS YAW JETS Z_E AND Y_E = ±61.5 (EFFECTIVE GEOMETRIC MOMENT ARM)

Figure 2.1: LM Reference Dimensions

Table 2.3 RCS Jet Thruster Locations(2)

Point of Application of RCS Jet Thrust	X_E Component(1)	Y_E Component(1)	Z_E Component(1)
Thrust of Jet 1	6.57352	1.67894	1.67894
2	6.31698	1.67894	1.67894
3	6.4516	1.5621	1.68529
4	6.4516	1.68529	1.5621
5	6.57352	1.67894	-1.67894
6	6.31698	1.67894	-1.67894
7	6.4516	1.5621	-1.68529
8	6.4516	1.68529	-1.5621
9	6.57352	-1.67894	-1.67894
10	6.31698	-1.67894	-1.67894
11	6.4516	-1.5621	-1.68529
12	6.4516	-1.68529	-1.5621
13	6.57352	-1.67894	1.67894
14	6.31698	-1.67894	1.67894
15	6.4516	-1.5621	1.68529
16	6.4516	-1.68529	1.5621

NOTES: (1) All station locations are in meters.

(2) Source - GAEC LMO 500-323, dated 30 August 1965.

Table 2.4 Ascent and Descent Tank Locations[2]

Tank Position in GAEC's Full Mission Engineering Simulation (FMES)[3] Coordinates	X Component[1]	Y Component[1]	Z Component[1]
Descent Fuel Tank 1	-2.3436072	1.3716	0
Descent Fuel Tank 2	-2.3436072	-1.3716	0
Descent Oxidizer Tank 3	-2.3436072	0	1.3716
Descent Oxidizer Tank 4	-2.3436072	0	-1.3716
Ascent Fuel Tank	-.6601968	-1.8099024	0
Ascent Oxidizer Tank	-.6601968	1.130808	0

NOTE: (1) All station locations are in meters

(2) Source - GAEC LMO 500-258, dated 5 August 1965.

(3) The FMES coordinate system origin is displaced 6.4516 meters from the origin of the LM axes in the +X direction. FMES and LM axes are parallel.

LM At Start Of Hover

Mass		7750.532809 kilograms
C.G.	X-component	5.18922 meters
	Y-component	0.05334 meter
	Z-component	0.00762 meter
Moment of Inertia	I_{xx}	17946.96183 N•m sec^2
	I_{xy}, I_{yx}	-1.355817922 N•m sec^2
	I_{xz}, I_{zx}	-503.008449 N•m sec^2
	I_{yy}	21543.94678 N•m sec^2
	I_{yz}, I_{zy}	-641.3018771 N•m sec^2
	I_{zz}	24528.10202 N•m sec^2

LM At Lunar Touchdown

Mass		6895.511193 kilograms
C.G.	X-component	5.40004 meters
	Y-component	0.05842 meter
	Z-component	0.01016 meter
Moment of Inertia	I_{xx}	16340.31759 N•m sec^2
	I_{xy}, I_{yx}	84.06071116 N•m sec^2
	I_{xz}, I_{zx}	-488.0944519 N•m sec^2
	I_{yy}	17639.19116 N•m sec^2
	I_{yz}, I_{zy}	-641.3018771 N•m sec^2
	I_{zz}	20974.50325 N•m sec^2

LM Ascent Stage At Lunar Liftoff

Mass		4627.549348 kilograms
C.G.	X-component	6.16204 meters
	Y-component	0.01524 meter
	Z-component	0.02794 meter
Moment of Inertia	I_{xx}	8650.118342 N•m sec^2
	I_{xy}, I_{yx}	-103.042162 N•m sec^2
	I_{xz}, I_{zx}	-165.4097864 N•m sec^2
	I_{yy}	4441.659512 N•m sec^2
	I_{yz}, I_{zy}	-24.404772259 N • m sec^2
	I_{zz}	7500.384744 N•m sec^2

LM Ascent Stage In Transfer Trajectory

Mass		2460.285009 kilograms
C.G.	X-component	6.46176 meters
	Y-component	0.03048 meter
	Z-component	0.05588 meter
Moment of Inertia	I_{xx}	4118.974847 N•m sec^2
	I_{xy}, I_{yx}	-70.50253194 N•m sec^2
	I_{xz}, I_{zx}	-126.0910667 N•m sec^2
	I_{yy}	3742.057464 N•m sec^2
	I_{yz}, I_{zy}	-32.53963012 N•m sec^2
	I_{zz}	2455.386256 N•m sec^2

LM Ascent Stage At Rendezvous

Mass		2326.021668 kilograms
C.G.	X-component	6.477 meters
	Y-component	0.03302 meter
	Z-component	0.05842 meter
Moment of Inertia	I_{xx}	3897.976525 N•m sec^2
	I_{xy}, I_{yx}	-69.14671402 N•m sec^2
	I_{xz}, I_{zx}	-123.3794309 N•m sec^2
	I_{yy}	3625.457123 N•m sec^2
	I_{yz}, I_{zy}	-37.96290181 N•m sec^2
	I_{zz}	2140.836498 N•m sec^2

Total mass of descent propellent	7872.367719 kilograms
Total mass of ascent fuel	2275.400759 kilograms

The data contained in this section are taken from GAEC Internal Memo LED-490-23 dated 1 August 1965.

2.4.3 Apollo Vehicle Dynamic Dynamic Data

2.4.3.1 Slosh

Ascent slosh frequency parameters	Table 2.5
Slosh mass in ascent tanks #5, #6	Table 2.5
Descent slosh pendulum pivot point	Table 2.6
Descent slosh frequency parameters	Table 2.6
Slosh mass in descent tanks #1, #2, #3, #4	Table 2.6

The information given in this section is taken from GAEC Internal Memo, LMO-500-258, dated 5 August 1965.

Table 2.5: Ascent Stage Slosh Parameters

Ascent Slosh Frequency Parameter (dimensionless)	Slosh Mass In Tanks	
	Ascent #5 (Slugs)	#6 (Slugs)
1	0	0
1.06	5.138	8.222
1.10	10.277	16.443
1.14	14.131	22.609
1.18	17.342	27.748
1.22	19.269	30.831
1.27	19.911	31.859
1.33	19.269	30.831
1.43	17.342	27.748
1.64	12.204	19.526
2.30	0	0

Table 2.6: Descent Stage Slosh Parameters

Descent Slosh Pendulum Pivot Point (1) (feet)	Descent Slosh Frequency Parameter (dimensionless)	Slosh Mass In Tanks	
		Descent #1, #2 (Slug)	#3, #4 (Slug)
-.806	1	0	0
-.806	1.09	8.262	13.218
-.806	1.16	15.491	24.785
-.763	1.23	18.589	29.741
-.678	1.29	20.654	33.046
-.509	1.33	21.687	34.698
-.254	1.35	21.687	34.698
.127	1.38	21,687	34.698
.509	1.44	20.654	33.046
.721	1.56	16.523	26.437
.806	2.50	0	0

Note: (1) Measured from tank center.

2.4.3.2 Structural Bending Data (LM/CSM Coupled)

First bending mode damping constant	0.005	$\sec^{-1}$
Second bending mode damping constant	0.015	$\sec^{-1}$
Third bending mode damping constant	0.015	$\sec^{-1}$

The above data are taken from a NAA letter from Mr. T. Lu to Mr. E. Copps dated 17 September 1965.

Bending data for Full CSM	Table 2.7
Bending data for Three-Quarter-Full CSM	Table 2.8
Bending data for Half-Full CSM	Table 2.9

The above tables are derived from the GN&C Data Exchange Program, NAA-S-37 submitted 26 August 1965, enclosure included NAA SD/ASD/65-058.

Table 2.7: CSM Full

Frequency of	1st bending mode	9.500176185	rad/sec
	2nd bending mode	30.98866993	rad/sec
	3rd bending mode	40.67105849	rad/sec
Displacement of	1st bending mode at thrust station	1.06	
	2nd bending mode at thrust station	-0.02	
	3rd bending mode at thrust station	-0.27	
Displacement of	1st bending mode at descent slosh station	0.90	
	2nd bending mode at descent slosh station	-0.12	
	3rd bending mode at descent slosh station	-0.20	
Displacement of	1st bending mode at ascent slosh station	-0.40	
	2nd bending mode at ascent slosh station	-0.30	
	3rd bending mode at ascent slosh station	0.35	
Displacement of	1st bending mode at NAV base	-1.9	
	2nd bending mode at NAV base	0.37	
	3rd bending mode at NAV base	-0.33	
Displacement of	1st bending mode at CSM slosh station	0.13	
	2nd bending mode at CSM slosh station	0.04	
	3rd bending mode at CSM slosh station	-0.05	
Slope of	1st bending mode at thrust station	-.7795275590	rad/m
	2nd bending mode at thrust station	-.6574803149	rad/m
	3rd bending mode at thrust station	-.3188976377	rad/m
Slope of	1st bending mode at NVB base	-.7795275590	rad/m
	2nd bending mode at NVB base	-.3385826771	rad/m
	3rd bending mode at NVB base	-.7874015748	rad/m

Table 2.8: CSM Three-Quarter-Full

Frequency of	1st bending mode	9.927432786	rad/sec
	2nd bending mode	31.51645750	rad/sec
	3rd bending mode	40.97265139	rad/sec
Displacement of	1st bending mode at thrust station	0.90	
	2nd bending mode at thrust station	-0.03	
	3rd bending mode at thrust station	0.25	
Displacement of	1st bending mode at descent slosh station	0.78	
	2nd bending mode at descent slosh station	-0.15	
	3rd bending mode at descent slosh station	0.20	
Displacement of	1st bending mode at ascent slosh station	-0.45	
	2nd bending mode at ascent slosh station	-0.13	
	3rd bending mode at ascent slosh station	-0.15	
Displacement of	1st bending mode at NAV base	-1.88	
	2nd bending mode at NAV base	0.44	
	3rd bending mode at NAV base	0.25	
Displacement of	1st bending mode at CSM slosh station	0.10	
	2nd bending mode at CSM slosh station	0.04	
	3rd bending mode at CSM slosh station	0.02	
Slope of	1st bending mode at thrust station	-.7283464566	rad/m
	2nd bending mode at thrust station	-.6968503937	rad/m
	3rd bending mode at thrust station	-.3661417322	rad/m
Slope of	1st bending mode at NVB base	-.7283464566	rad/m
	2nd bending mode at NVB base	.2913385826	rad/m
	3rd bending mode at NVB base	.4724409448	rad/m

Table 2.9: CSM Half-Full

Frequency of	1st bending mode	10.3735387	rad/sec
	2nd bending mode	31.9625631	rad/sec
	3rd bending mode	41.123447	rad/sec
Displacement of	1st bending mode at thrust station	0.85	
	2nd bending mode at thrust station	0.04	
	3rd bending mode at thrust station	0.20	
Displacement of	1st bending mode at descent slosh station	0.71	
	2nd bending mode at descent slosh station	-0.06	
	3rd bending mode at descent slosh station	0.17	
Displacement of	1st bending mode at ascent slosh station	-0.41	
	2nd bending mode at ascent slosh station	-0.15	
	3rd bending mode at ascent slosh station	-0.04	
Displacement of	1st bending mode at NAV base	-1.78	
	2nd bending mode at NAV base	0.45	
	3rd bending mode at NAV base	0.40	
Displacement of	1st bending mode at CSM slosh station	0.29	
	2nd bending mode at CSM slosh station	0.01	
	3rd bending mode at CSM slosh station	-0.03	
Slope of	1st bending mode at thrust station	-.6811023622	rad/m
	2nd bending mode at thrust station	-.5905511811	rad/m
	3rd bending mode at thrust station	-.2165354330	rad/m
Slope of	1st bending mode at NVB base	-.6811023622	rad/m
	2nd bending mode at NVB base	.3031496062	rad/m
	3rd bending mode at NVB base	.4527559055	rad/m

2.4.4 LM Descent Propulsion System (DPS)

Ignition step delay ($\Delta T_{\text{build up}}$)	0.300 second
Tail off step delay ($\Delta T_{\text{tail off}}$)	0.400 second
Throttling time constant	3.3333333 seconds
Throttling incrementing rate	42702.92668 $\frac{\text{Newtons}}{\text{second}}$
Minimum throttle setting	4670.632606 Newtons
Maximum throttle setting	46706.32606 Newtons

The above data are taken from GAEC Internal Memo LMO-500-323, 30 August 1965.

Thrust build-up vs. time following ignition	Figure 2.2
Thrust decay vs. time following shutdown	Figure 2.2
Vacuum thrust vs. propellant flow rate	Figure 2.3

The figures referenced above are taken from TRW Systems Document, #05952-H041-R8-000 "Apollo Mission AS-207/208A Spacecraft Reference Trajectory," dated 7 October 1966 and modified for 10% thrust (during the start up mode) by MIT/IL.

Specific impulse Nominal rated thrust Propellant flow rate	vs. percent thrust	Figure 2.4

This figure is taken from TRW Systems Document #2131-H005-R8-000, "Apollo Mission Data Specification C AS-207/028A," dated 9 June 1966 and modified for 10% thrust (during the start-up mode) by MIT/IL

2.4.4.1 LM Descent Engine (DE) Location Dispersions (3-sigma)

Position error	0.00508 meter
Misalignment from center line	0.00872664626 radian
Misalignment from center line with respect to x-axis	0.005235987756 radian
Thrust dependent misalignment	0.01308996939 radian

The above data are taken from GAEC Internal Memo LMO-500-323, 30 August 1965

2.4.4.2 LM Descent Propulsion System For CSM SPS Backup

DE vacuum performance for SPS backup	Figure 2.5

This figure is taken from TRW Systems Document #2131-H005-R8-000, dated 9 June 1966 and modified for 10% thrust (during start up mode) by MIT/IL.

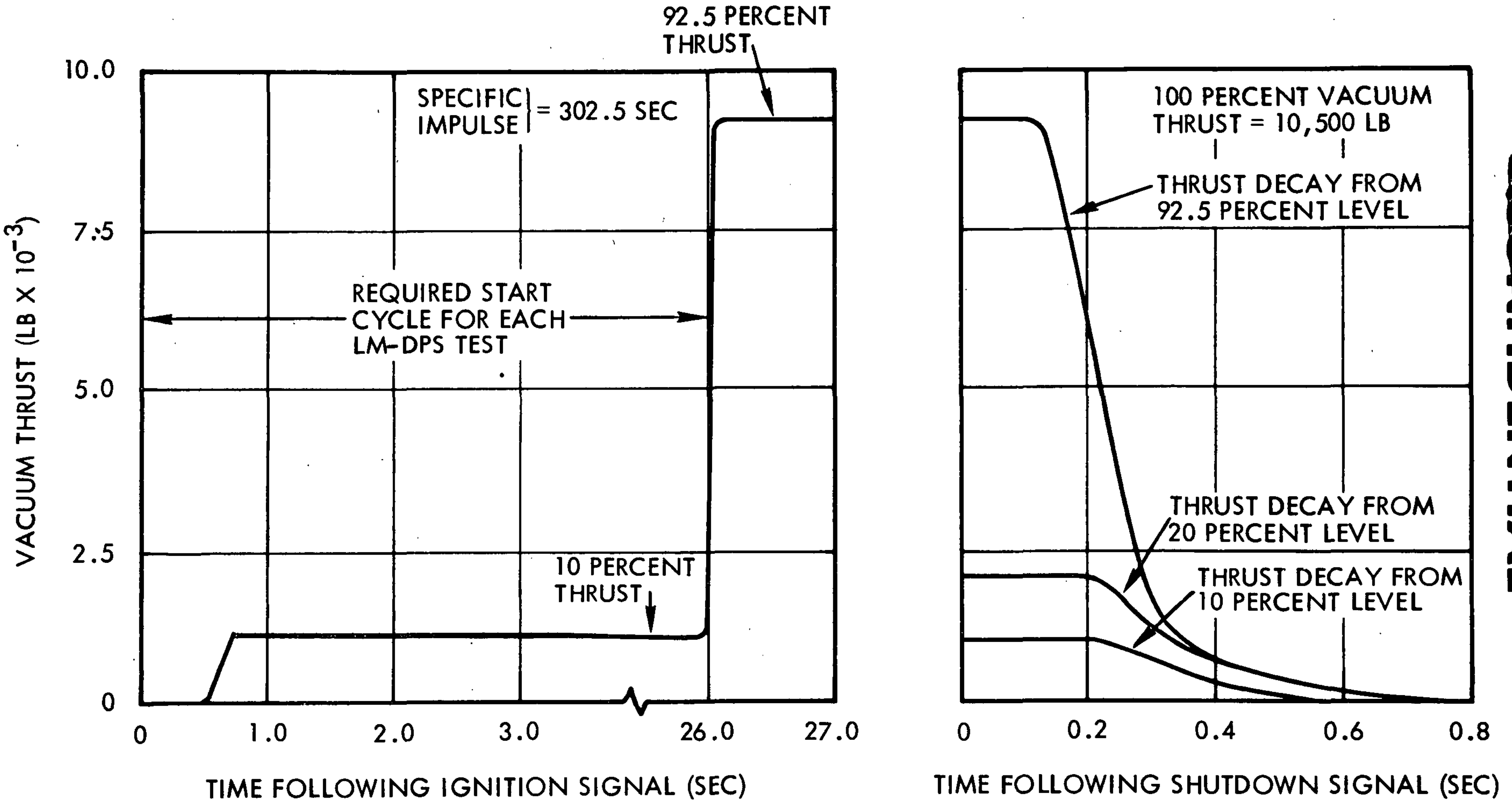


Figure 2.2: LM-DPS Vacuum Thrust Characteristics As Amended by MIT/IL for 10% Thrust.

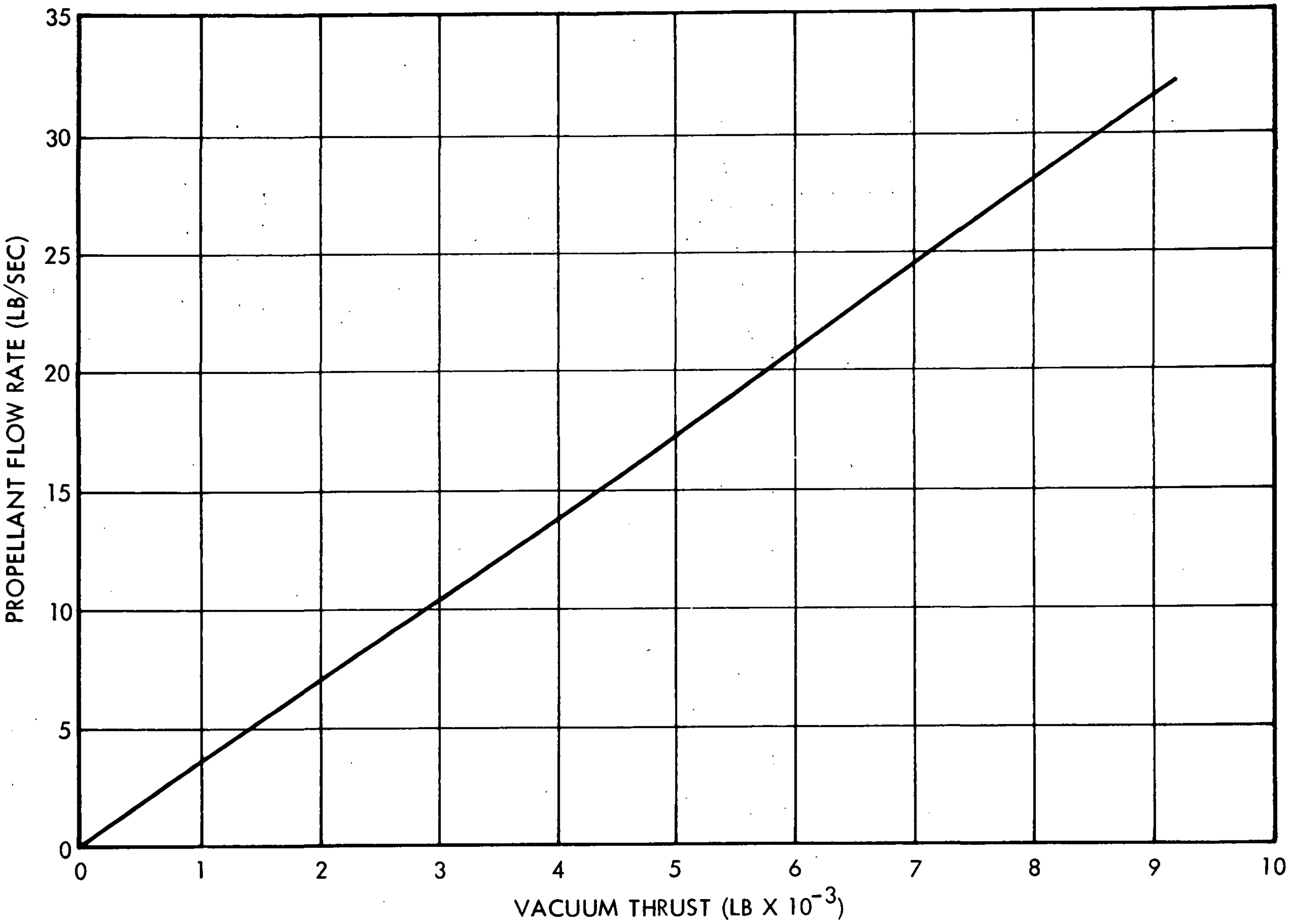
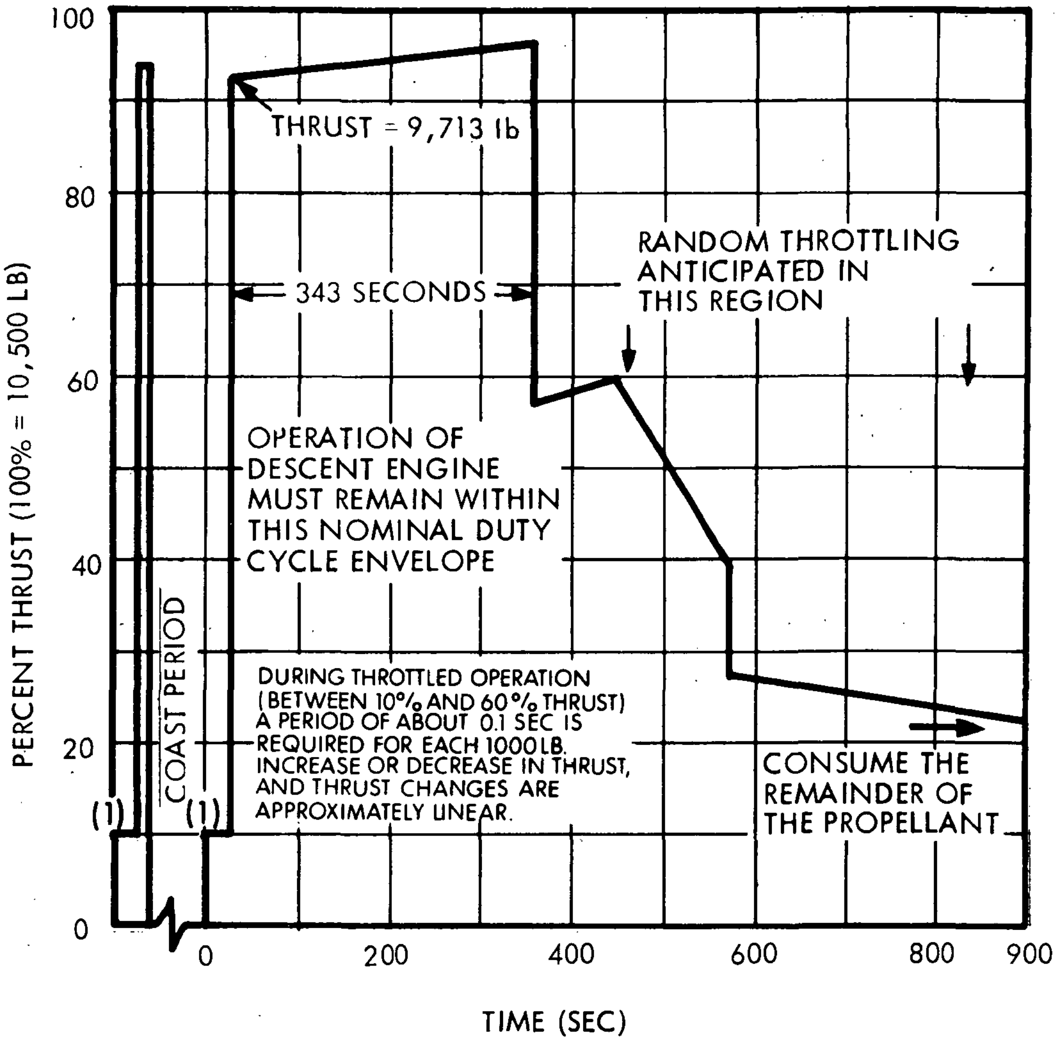


Figure 2.3: LM-DPS Vacuum Thrust and Weight Flow Characteristics



Notes:

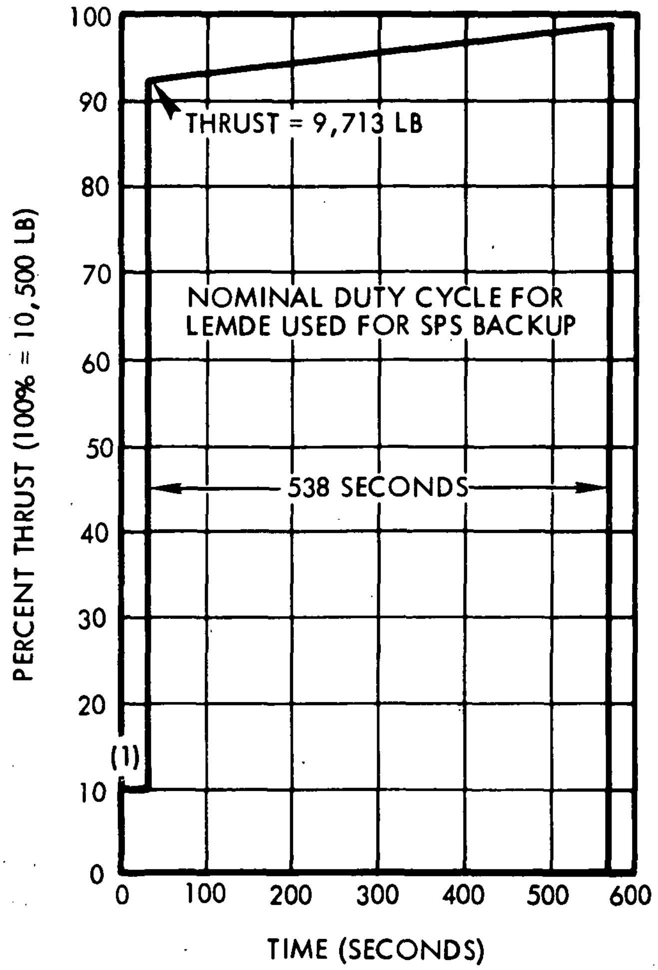
(1) LMDE must be started as shown in Figure 2.2.

Percent Thrust (%)	Nominal Rated Thrust (lb)	Specific Impulse[2] I_{SP} (sec)	Propellant Flow Rate $\dot{w}$ (lb/sec)	Propellant Mixture Ratio O/F = 1.6/1 (Nominal)
92.5	9,713	302.5	32.11	Maximum Thrust
60	6,300	293.0	21.50	Throttleable Range
50	5,250	289.0	18.16	
40	4,200	294.0	14.29	
25	2,625	295.0	8.90	
10	1,050	288.0	3.65	

(2) Subtract 1-1/2 seconds to obtain an estimate of 3σ minimum I_{SP}.

Duty cycle data and values of I_{SP} are based on results of recent development tests.

Figure 2.4 LM Descent Engine Vacuum Performance Summary



Notes:

(1) LMDE must be started as shown in Figure 2.2.

Fig. 2.5 LM Descent Engine Vacuum Performance for SPS Backup

2.4.4.3 Descent Engine Gimbal

Trim gimbal step delay	0.1 second
Trim gimbal rate	0.003490658504 rad/sec
Trim gimbal limit about pitch axis	0.1047197551 radian
Trim gimbal limit about yaw axis	0.1047197551 radian

The above data are taken from GAEC Internal Memo LMO-500-323, 30 August 1965.

2.4.5 LM Ascent Propulsion System (APS)

Ignition step delay ($\Delta T_{\text{build up}}$)	0.450 second
Tail off step delay ($\Delta T_{\text{tail off}}$)	0.350 second
3 sigma ascent engine position error	0.00508 meter
3 sigma ascent engine misalignment	0.61745329252 radian

The above data are taken from GAEC Internal Memo LMO-500-323, 30 August 1965.

Buildup impulse to 90% rated thrust		116 lb-sec
Tail off impulse to 10% rated thrust		308 lb-sec
Propellant flow rate	steady state operation	11.33 lb/sec
Specific impulse		306.3 seconds
Nominal thrust		3500 ± 88 lbs

The above data are taken from TRW Systems Document #2131-H005-R8-000, "Apollo Mission Data Specification C AS-207/208A" dated 9 June 1966.

Thrust buildup vs time following ignition	Figure 2.6
Thrust decay vs time following shutdown	Figure 2.6

The figure referenced above is taken from TRW Systems Document #05952-H041-R8-000 "Apollo Mission AS207/208A Spacecraft Reference Trajectory," dated 7 October 1966.

2.4.6 Abort Staging

Delay measured from receipt of abort stage signal to mechanical separation	0.46 second
Abort stage engine on delay measured from receipt of abort stage signal to application of ascent engine thrust	0.30 second

The above data are taken from GAEC Internal Memo LAV-500-240 dated 5 November 1965.

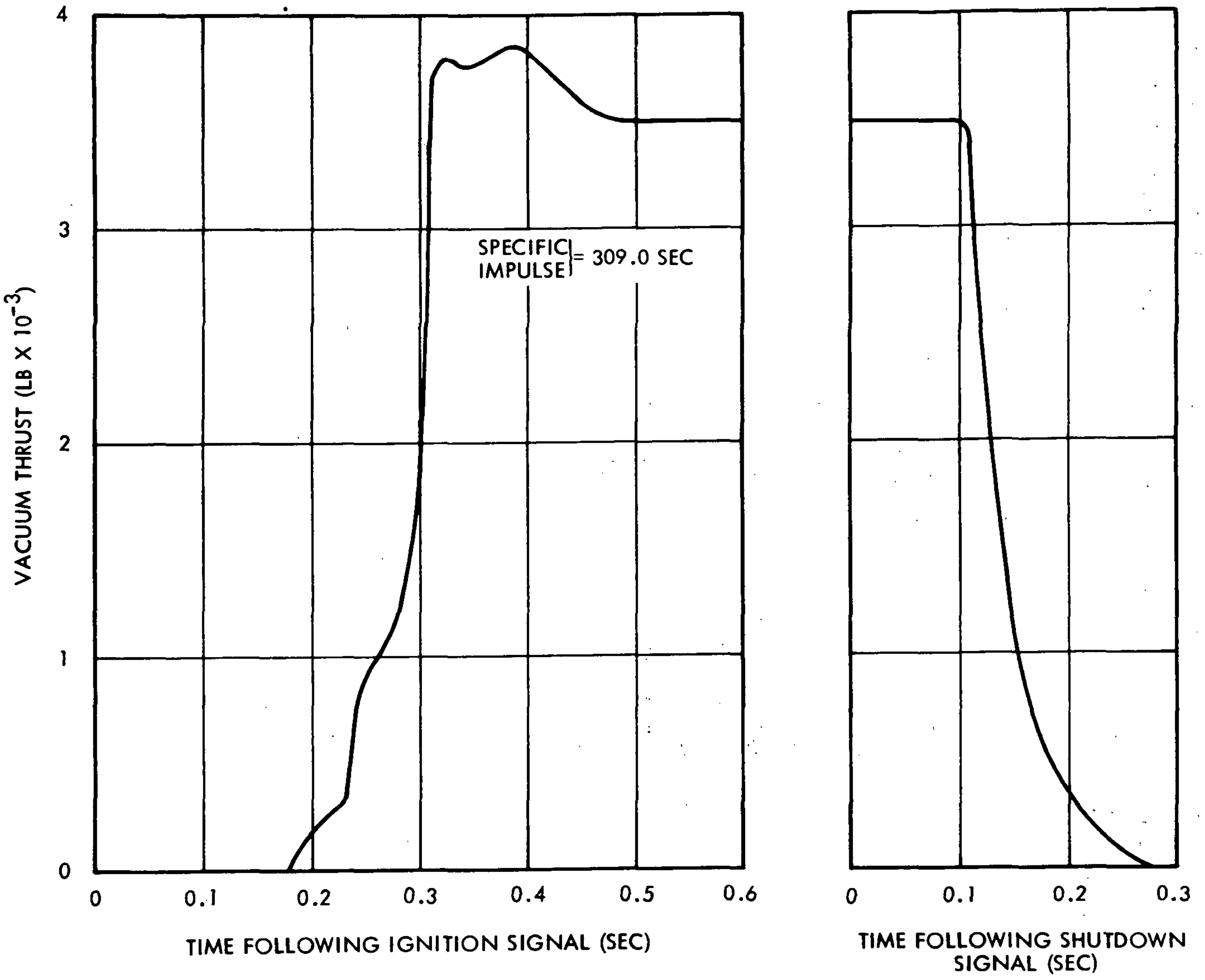


Figure 2.6 LM-APS Vacuum Thrust Characteristics

[redacted]

Constants for staging force polynomial	Table 2.10
Constants for staging torque polynomial	Table 2.11
Staging force discontinuities measured from ascent engine ignition, (for lunar launch staging)	0.1, 0.8 second
Staging force discontinuities measured from ascent engine ignition, (for abort staging)	0.15, 0.665 second

The above data are taken from GAEC Internal Memo LAV-500-87 dated 12 March 1965.

Table 2.10: Constants for Staging Force Polynomial

203950.9571	Newtons
31057.48272	Newtons
-124550.2028	Newtons
189360.7905	Newtons
-102753.9173	Newtons
222411.0765	Newtons
26689.32918	Newtons
-100529.8065	Newtons
106757.3167	Newtons
-22241.10765	Newtons

[redacted]

[redacted]

Table 2.11: Constants for Staging Torque Polynomial

9761.889038	Newton meter
1626.981506	Newton meter
-8080.674815	Newton meter
16852.81677	Newton meter
-11619.35959	Newton meter
11171.93967	Newton meter
1355.817922	Newton meter
-5287.689895	Newton meter
5762.226168	Newton meter
-1803.237836	Newton meter
-108709.4809	Newton meter
-16269.81506	Newton meter
62177.80990	Newton meter
-83287.89494	Newton meter
38735.71803	Newton meter
-117901.9264	Newton meter
-16256.25688	Newton meter
87992.58313	Newton meter
-183984.4920	Newton meter
137479.9372	Newton meter

[redacted]

2.4.7 LM Reaction Control System (RCS)

RCS jet thrust chamber configuration	Figure 2.7

The figure referenced above is taken from TRW Systems Document #2131-H005-R8-000 "Apollo Mission Data Specification C AS 207/208A" dated 9 June 1966.

2.4.7.1 RCS Jet Vacuum Performance Data

Step delay in RCS thrust application from receipt of command	0.015 second
Step delay in removal of RCS thrust application from receipt of command	0.01 second
Minimum time which jet remains on	0.013 second

This information is taken from GAEC Internal Documents LMO-500-323 dated 30 August 1965, and LMO-310-229.

RCS jet fuel usage per second (no dribble mass)	$0.166151051 \frac{\text{kilogram}}{\text{second}}$
RCS - dribble mass - per jet firing	0.001814369476 kilogram

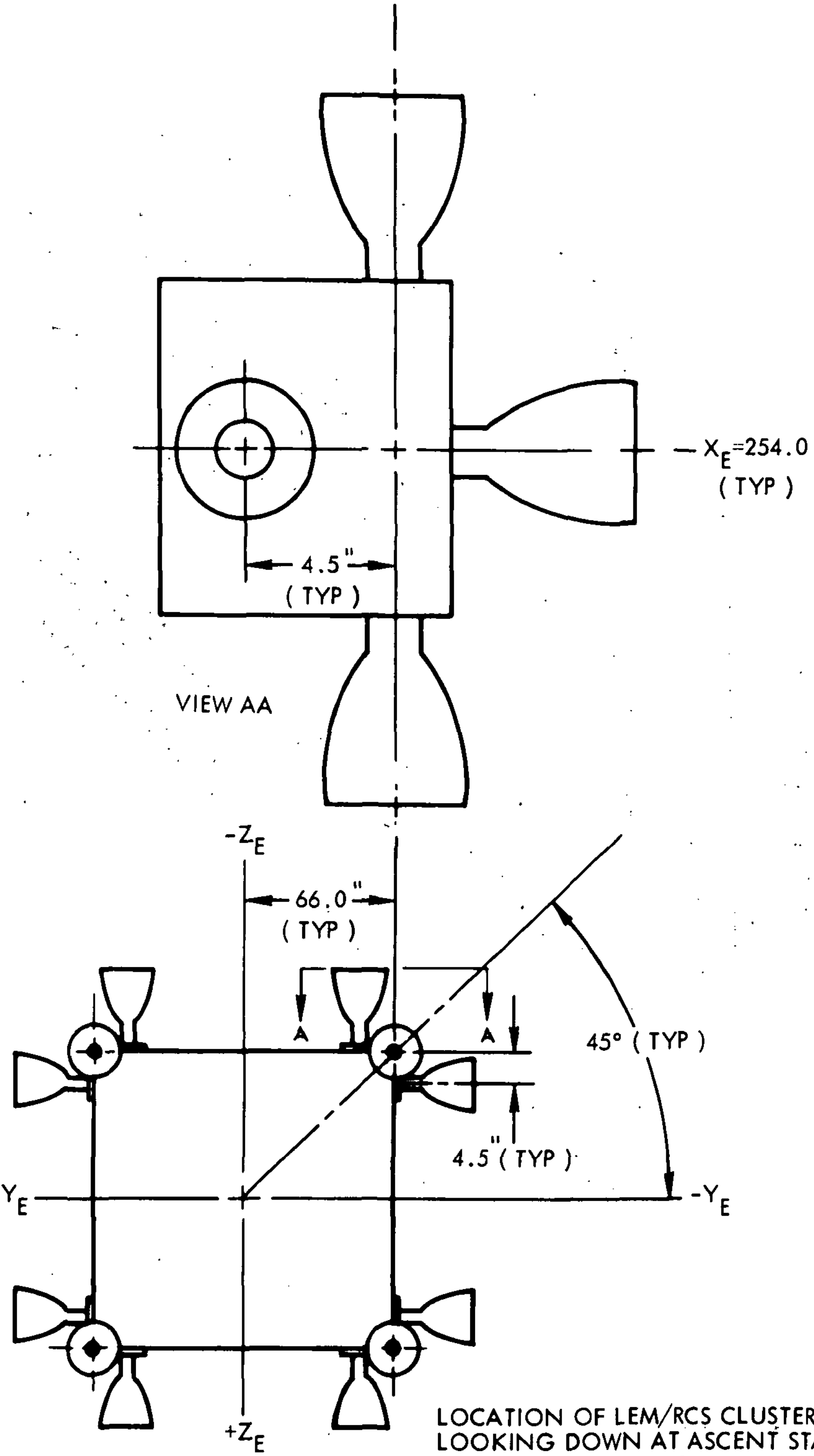
The information is taken from MIT/IL SGA Group Internal Memo "RCS Propellant Model" dated 27 January 1966, and GAEC Internal Memo LMO-310-229.

Constants for jet impingement forces and torques	0.094 0.147 0.170 0.368 1.593

Data source unknown.

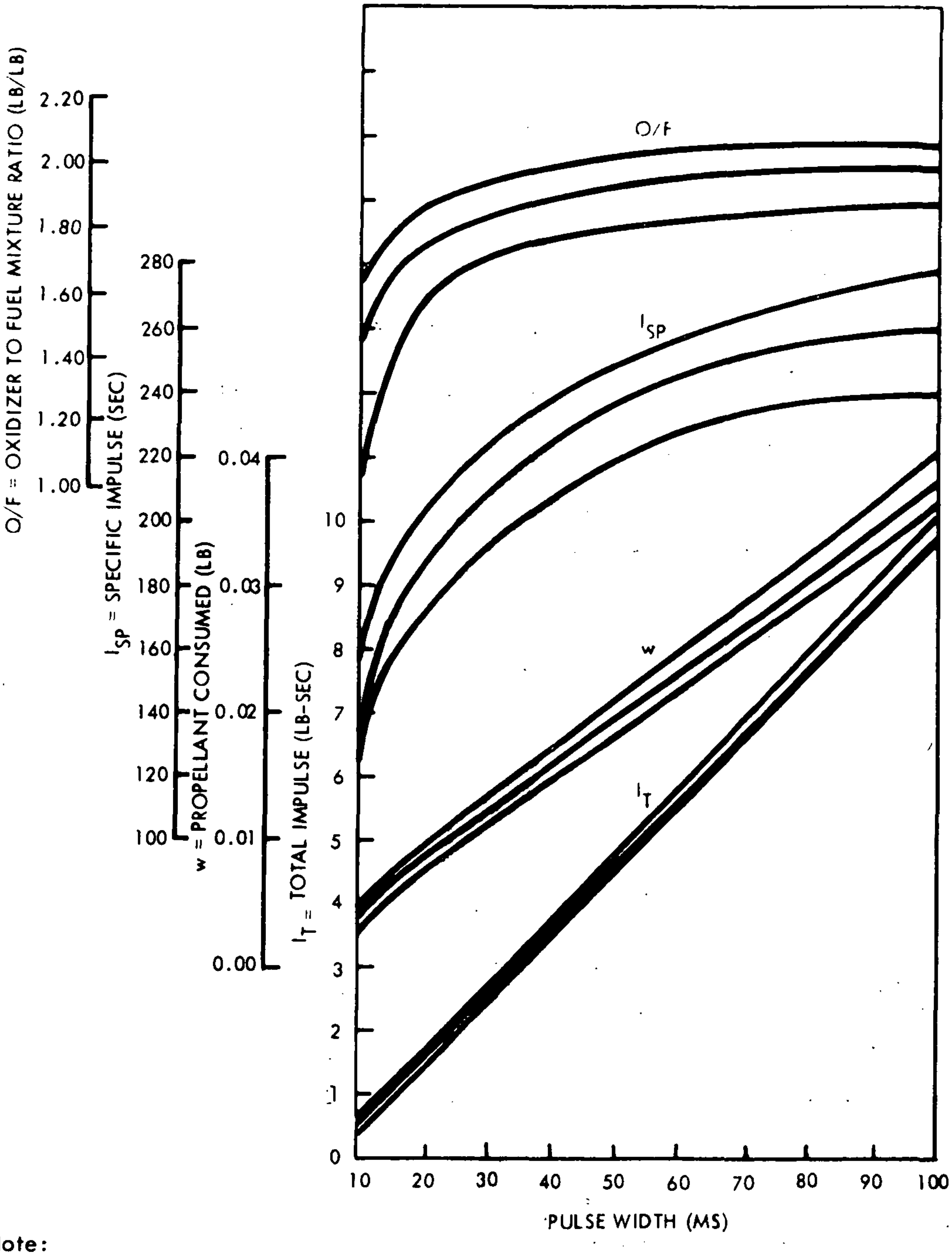
Total impulse Specific impulse Propellant consumed	vs electrical pulsewidth	Figures 2.8, 2.9
Nominal thrust Specific impulse Propellant flow rate	steady state performance	Figure 2.9

The above data are taken from TRW Systems Document #2131-H005-R8-000 "Apollo Mission Data Specification C AS-207/208A" dated 9 June 1966.



LOCATION OF LEM/RCS CLUSTERS
LOOKING DOWN AT ASCENT STAGE
IN LANDING POSITION

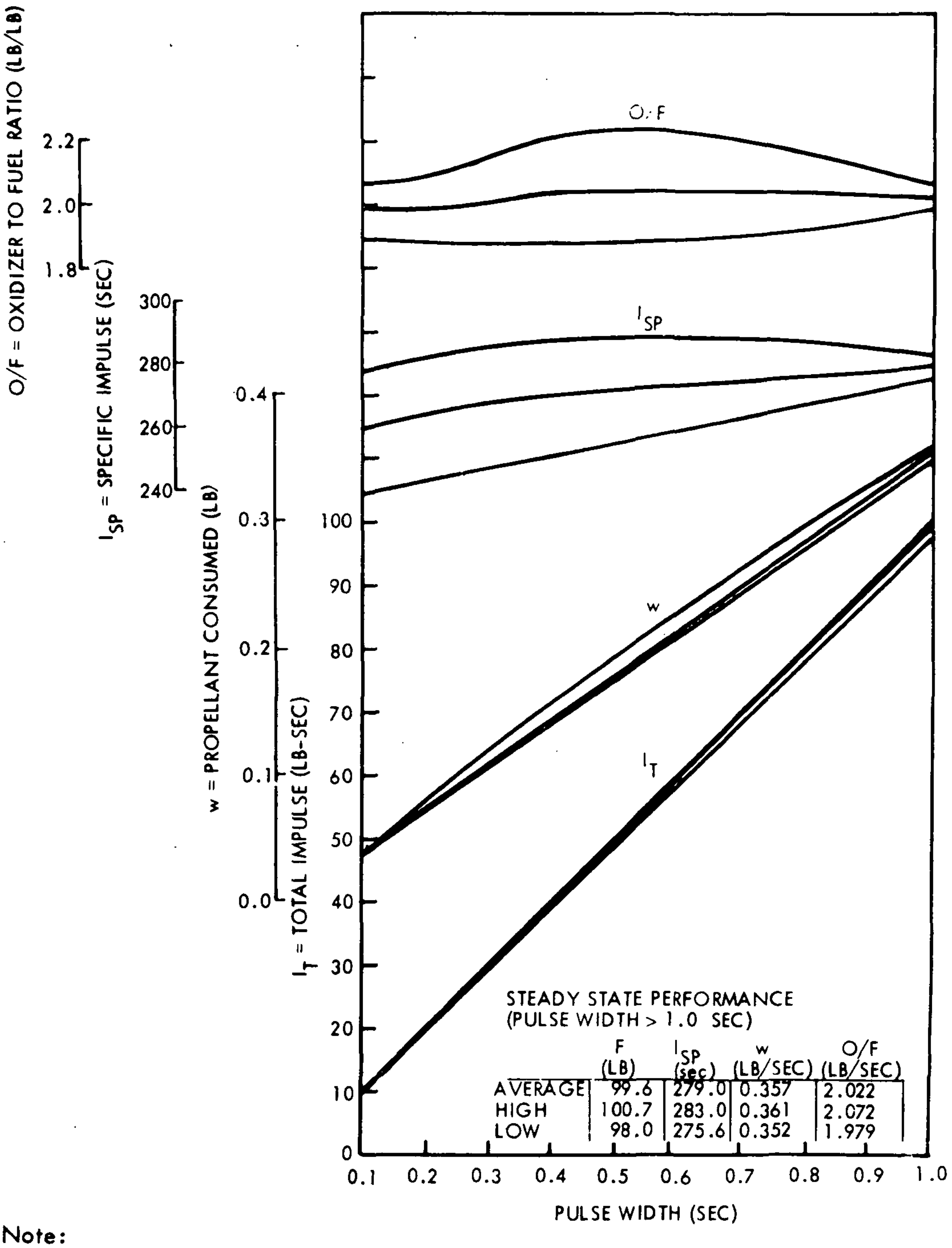
Fig. 2.7 LM/RCS Thrust Chamber Configuration



Note:

Data are high, low, and average values resulting from a large number of qualification tests. High and low values shall be used as 3σ values.

Fig. 2.8 LM/RCS Vaccuum Performance Data for Pulse Widths Less than 100 ms



STEADY STATE PERFORMANCE
(PULSE WIDTH > 1.0 SEC)

	F (LB)	I_{SP} (sec)	w (LB/SEC)	O/F (LB/SEC)
AVERAGE	99.6	279.0	0.357	2.022
HIGH	100.7	283.0	0.361	2.072
LOW	98.0	275.6	0.352	1.979

Note:

Data are high, low, and average values resulting from a large number of qualification tests. High and low values shall be used as 3σ values.

Fig. 2.9 LM/RCS Vaccuum Performance Data for Pulse Widths Greater than 100 ms

[redacted]

Three-sigma RCS position error	0.00762 meter
Three-sigma RCS misalignment	0.05235987756 radian

The above data are taken from GAEC Internal Memo LMO-500-323 dated 30 August 1965.

2.5 Physical Constants

The following three documents have been used as data source for this whole section:

1) NASA SP-7012, "The International System of Units - Physical Constants and Conversion Factors," MSFC 1964.
2) NASA M-DE-8020-008B, "Natural Environment and Physical Standards for the Apollo Program," April 1965.
3) NASA Working Paper 10,020B, "Directory of Standard Geodetic and Geophysical Constants for Gemini and Apollo," 6 April 1966.

2.5.1 Geophysical Parameters

Parameters	Symbol	Value
Equatorial earth radius (gravitational)	R_e	$0.63781\ 65 \times 10^{7}$ meter
Acceleration of gravity (standard)	g_o	$0.98066\ 50000 \times 10^{1}\ \frac{\text{meters}}{\text{sec}^{2}}$
Gravitation parameter	μ_e	$0.39860\ 32 \times 10^{15}\ \frac{\text{meter}^{3}}{\text{sec}^{2}}$
Mass of the earth	M_e	0.5975×10^{25} kilogram
Rotational rate of the earth (1966-72)	ω_e	$0.72921\ 1506 \times 10^{-4}\ \frac{\text{radian}}{\text{second}}$

Gravitational potential harmonic coefficients:

second-order term	J	$0.16234\ 5 \times 10^{-2}$
third-order term	H	-0.575×10^{-5}
fourth-order term	D	0.7875×10^{-5}
	J_{22}	0.19×10^{-5}
	λ_{22}	-21 degrees

2.5.2 General Constants

π	$0.31415\ 92653 \times 10^{1}$

2.5.3 Conversion Factors with 10 Significant Figures

To Convert	Symbols	Multiply By
Feet to Meters	FTM	0.30480 00000
Slugs to Kilograms	STK	$0.14593\ 90293 \times 10^{2}$
Pounds to Kilograms	PTK	0.45359 23700
Degrees to Radians	DTR	$0.17453\ 29251 \times 10^{-1}$
Inches to Meters	ITM	0.02540 00000
Pounds to Newtons	PTN	$0.44482\ 21615 \times 10^{1}$
Foot Pounds to Newton Meters	FPTNM	$0.13558\ 17948 \times 10^{1}$
Nautical Mile to Kilometers		$0.18520\ 00000 \times 10^{1}$
Statute Miles to Kilometers		$0.16093\ 44000 \times 10^{1}$
Slug-Feet^2 to Kilogram-Meter^2		$0.13558\ 17948 \times 10^{1}$

2.6 Carry-On Data

This page is intentionally left blank. Carry-on data are not available at this time.

2.7 LM PGNC System Description

2.7.1 PGNCS Hardware Configuration

System 605 will be the PGNC system for Mission 278. It is a normal LM system except for the Signal Conditioning Assembly which processes FLIGHT QUALIFICATION measurements as well as OPERATIONAL measurements. The Uplink Data link to the LGC will be operational for Mission 278, with no provision to block uplink. The system is comprised of the following major assemblies:

Inertial Measurement Unit (IMU)
Pulse Torque Assembly (PTA)
Coupling Data Unit (CDU)
LM Navigation Base (NB)
Alignment Optical Telescope (AOT)
LM Guidance Computer (LGC)
Display Keyboard Assembly (DSKY)
Computer Control and Reticle Dimmer Assembly (CCRD)
Power and Servo Assembly - LM (PSA)
LM Signal Conditioner Assembly (SCA-FQ)
LM G&N Interconnect Harness Group

2.7.2 PGNCS/Spacecraft Signal Interfaces

2.7.2.1 Interface Control Documents (ICD's)

Below are presented the Interface Control Documents (ICD's) which are pertinent to definition and understanding of the electrical/functional interfaces between PGNCS and the spacecraft and the astronauts. Additional existing ICD's pertaining to mechanical interfaces, thermal interfaces, etc. are not listed because they are not considered to be relevant to this document.

General Interfacing Area	ICD Title	ICD No.	Description
PGNCS/LM/AGS/RR/LR FUNCTION	LM-PGNCS Functional Interface Requirements.	LIS-540-10001 (IRN's -1, -2, -3, -4, -5, -6, -7, -8)	A complete definition of the functional interrelationships between the PGNCS, LM (RCS, Descent Engine, Ascent Engine, AGS RR and LR)
	G&N Functional Flow Diagram	LID-540-10001 (Rev. A)	Schematic Drawing of G&N/LM Interfaces
TOTAL ATTITUDE/ATTITUDE ERROR	LM-PGNCS Electrical Interface for Total Attitude Signals, Attitude Error Signals (Displays) and IMU Cage Signal (Command)	LIS-350-10001 (Rev. A) (IRN-A-1)	Signal interface for: (a) SIN AIG * (b) COS AIG* (c) SIN AMG* (d) COS AMG* (e) SIN AOG* (f) COS AOG* (g) E_Y, PITCH ERROR* (h) E_Z, ROLL ERROR* (i) E_X, YAW ERROR* (j) IMU CAGE
	LM-PGNCS 800 cps Excitation Signal, Electrical Interface	LIS-370-10007 (IRN-1)	Signal Interface for: (a) 800~ Reference
LGC/LM	LGC-LM Electrical Interface	LIS-370-10004 (Rev. B)	Signal interface and electric loads for complete LGC/LM interface. For signal list (see also sec. 2.7.2.2)

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* 800 cps modulated signals.

General Interfacing Area	ICD Title	ICD No.	Description
PGNCS/AGS	Abort Guidance Section Electrical Interface with PGNCS	LIS-300-10002 (IRN-1)	Signal interface for: (a) CDU Zero Signal (b) Incremental Total Attitude: +ΔAIG (c) Incremental Total Attitude: -ΔAIG (d) Incremental Total Attitude: +ΔAMG (e) Incremental Total Attitude: -ΔAMG (f) Incremental Total Attitude: +ΔAOG (g) Incremental Total Attitude: -ΔAOG (Also see sec. 2.7.2.2)
PGNCS/RENDEZVOUS RADAR	PGNCS to Rendezvous Radar Angle	LIS-370-10006 (IRN's -1, -2, -3)	Signal interface for: (a) Sine Shaft 1X * (b) Cos Shaft 1X * (c) Sine Shaft 16X * (d) Cos Shaft 16X * (e) Sine Trunnion 1X * (f) Cos Trunnion 1X * (g) Sine Trunnion 16X * (h) Cos Trunnion 16X * (i) Shaft axis angular designate * (j) Trunnion axis angular designate *
PGNCS/TELEMETRY	LM PGNCS Measurement Interface Provisions	LIS-370-10003 (IRN's -1, -2, -3, -4)	Signal interface for all G&N PCM and DFI measurements.
PGNCS/ LM DISPLAY	LM-PGNCS Lateral and Forward Velocity Electrical Interface (DISPLAYS)	LIS-350-10002 (IRN-1)	Signal Interface for: (a) V_Z - Forward velocity + (b) V_Y - Lateral velocity + (Not used on Mission 278)

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* 800 cps modulated signals

\+ d-c signals

General Interfacing Area	ICD Title	ICD No.	Description
PGNCS/LM POWER	PGNCS Prime Power Requirements and Characteristics	LIS-390-10002 (IRN-1)	Total AC and DC Power specification from LM for G&N
S-Band Steerable Antenna/PGNCS	S-Band Steerable* Antenna Functional Interface with PGNCS	LIS-380-10001 (IRN-1)	Defines LGC Display requirements with regards pointing the S-Band Antenna

2.7.2.2 LGC LM Signal Interface

The following section lists the complete signal interface between the LGC and the LM as described in detail in ICD LIS-370-10004B. Figure 2-10 presents a schematic representation of the interface.

2.7.2.2.1 LGC/LM Interface - Inputs to LGC

(1) Automatic Mode	CONTROL MODE AND STATUS SIGNALS
(2) Attitude Hold Mode	
(3) Out of Detent	
(4) Start "Abort" Program	
(5) Start "Abort Stage" Program	
(6) Engine Armed	
(7) Digital Autopilot in Control	
(8) In Auto Throttle	
(9) Display Inertial Data*	
(10) Rate of Descent Bar*	
(11) Rate of Descent - plus *	
(12) Rate of Descent - minus*	
(13) Thruster 2-4 Fail	
(14) Thruster 5-8 Fail	
(15) Thruster 1-3 Fail	
(16) Thruster 6-7 Fail	
(17) Thruster 14-16 Fail	
(18) Thruster 13-15 Fail	
(19) Thruster 9-12 Fail	
(20) Thruster 10-11 Fail	
(21) Stage Verified	
(22) +X Translation Command	TRANSLATION HAND CONTROLLER
(23) -X Translation Command	

* Not used on Mission 278

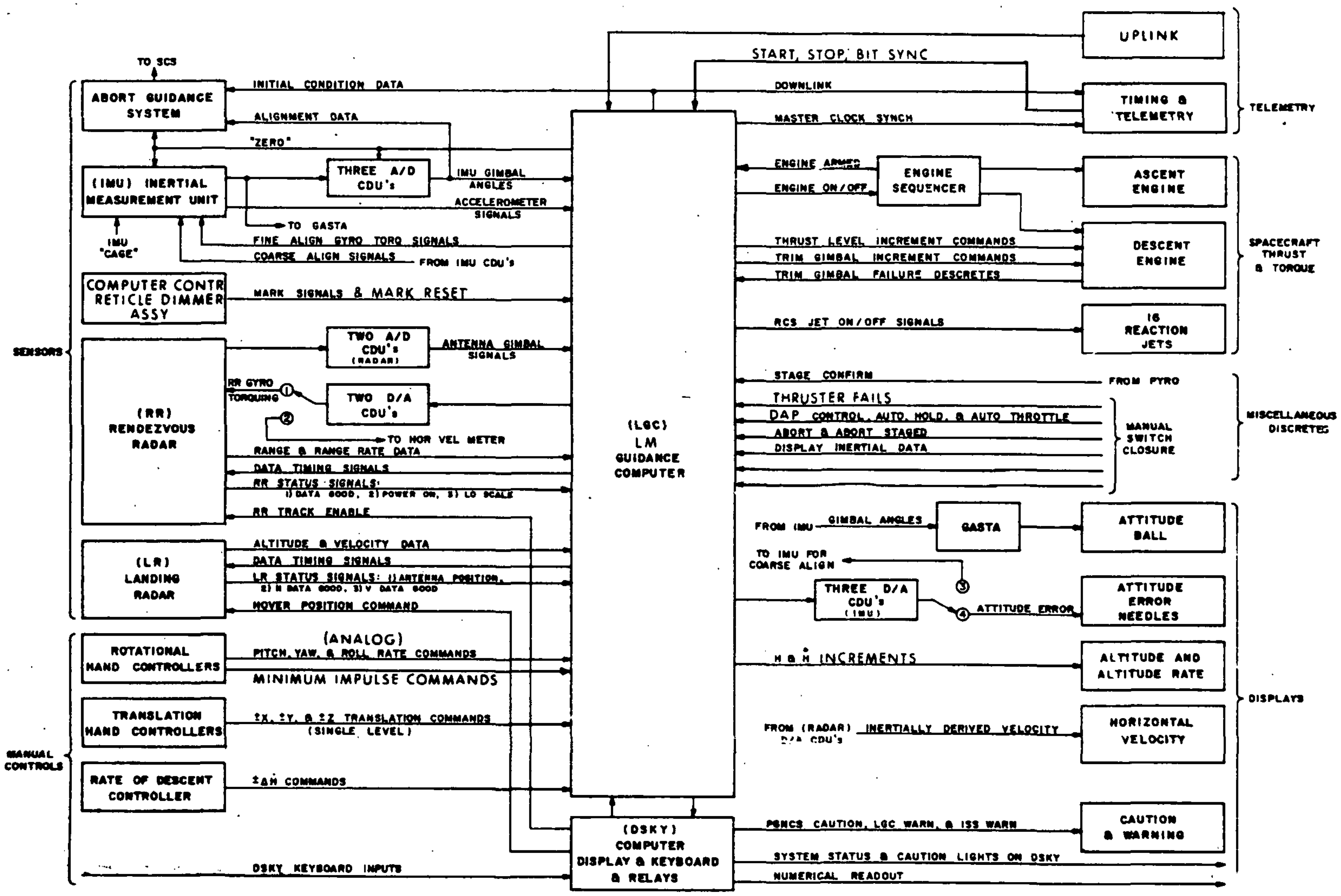

Fig. 2.10 PGNCS and LM Functional Interface Diagram

(24) +Y Translation Command	TRANSLATION HAND CONTROLLER
(25) -Y Translation Command	
(26) +Z Translation Command	
(27) -Z Translation Command	
(28) Pitch Rate Command	ATTITUDE HAND CONTROLLER (800 cps modulated signals)
(29) Roll Rate Command	
(30) Yaw Rate Command	
(31) Pitch Gimbal Off	DESCENT ENGINE
(32) Yaw Gimbal Off	
(33) RR in "1" (Data Flow)	RENDEZVOUS RADAR
(34) RR in "0" (Data Flow)	
(35) RR Data Good	
(36) RR Power On and Auto Mode	
(37) RR Range Low Scale	
(38) LR in "1" (Data Flow)	LANDING RADAR
(39) LR in "0" (Data Flow)	
(40) LR Range Data Good	
(41) LR Velocity Data Good	
(42) LR Position #1 Indication	
(43) LR Position #2 Indication	
(44) LR Range Low Scale Factor	
(45) Uplink Data (Binary "1")	UPLINK
(46) Uplink Data (Binary "0")	
(47) Start Pulse	DOWNLINK
(48) Stop Pulse	
(49) Bit Sync Pulse	
(50) Plus Roll Impulse	MINIMUM INPUT CONTROLLER
(51) Minus Roll Impulse	
(52) Plus Pitch Impulse	
(53) Minus Pitch Impulse	
(54) Plus Yaw Impulse	
(55) Minus Yaw Impulse	

2.7.2.2.2 LGC/LM Interface - Output from LGC

(1) Increase Throttle	DESCENT ENGINE
(2) Decrease Throttle	
(3) + Pitch Trim	
(4) - Pitch Trim	
(5) + Roll Trim	
(6) - Roll Trim	

(7) Engine On	ENGINE SEQUENCER (DESCENT AND ASCENT)
(8) Engine Off	
(9) RCS Jet #2 (+X)	RCS JET DISCRETES
(10) RCS Jet #6 (+X)	
(11) RCS Jet #10 (+X)	
(12) RCS Jet #14 (+X)	
(13) RCS Jet #5 (-X)	
(14) RCS Jet #9 (-X)	
(15) RCS Jet #1 (-X)	
(16) RCS Jet #13 (-X)	
(17) RCS Jet #12 (+Y)	
(18) RCS Jet #16 (+Y)	
(19) RCS Jet #4 (-Y)	
(20) RCS Jet #8 (-Y)	
(21) RCS Jet #11 (+Z)	
(22) RCS Jet #7 (+Z)	
(23) RCS Jet #3 (-Z)	
(24) RCS Jet #15 (-Z)	
(25) RR Reset Strobe	RENDEZVOUS RADAR
(26) RR Range Gate Strobe	
(27) RR Range Rate Gate Strobe	
(28) RR Counter Readout Command	
(29) Auto Angle Track Enable	
(30) LR Reset Strobe	LANDING RADAR
(31) LR Range Gate Strobe	
(32) LR X_A Velocity Gate Strobe	
(33) LR Y_A Velocity Gate Strobe	
(34) LR Z_A Velocity Gate Strobe	
(35) LR Counter Readout Command	
(36) LR Antenna Position Command	
(37) Serial Digital Data *	DOWNLINK and TIMING
(38) Sync Signal - 1024 KC	
(39) LGC (warning)	CAUTION and WARNING SIGNALS
(40) PGNCS (Caution)	
(41) Inertial Reference (Warning)	
(42) Altitude "0"	ALTITUDE AND ALTITUDE RATE METERS
(43) Altitude "1"	
(44) Altitude Rate "0"	
(45) Altitude Rate "1"	

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