



National Aeronautics and
Space Administration

NSTS 08209, Volume I
REVISION B
MARCH 16, 1999

Lyndon B. Johnson Space Center
Houston, Texas 77058

REPLACES
NSTS 08209, VOLUME I
REVISION A

SPACE SHUTTLE

SHUTTLE SYSTEMS DESIGN CRITERIA

VOLUME I

SHUTTLE PERFORMANCE ASSESSMENT DATABOOK

REVISION LOG

REV LTR	CHANGE NO	DESCRIPTION	DATE
		BASELINE ISSUE (Reference: Level II PRCBD S40620J, dated 1/11/89) also includes PRCBD S40620JR1.	04/07/89
A	24	REVISION A (Reference: SSP DOC-206, dated 6/15/94) also includes Space Shuttle PRCBD S052730A, SSP DOC-106, SSP DOC-201, SSP DOC-205 and Changes 1 thru 23.	08/26/94
B	47	REVISION B (Reference: Space Shuttle PRCBD S052189CF, dated 2/11/99) also includes Changes 25 thru 46.	03/16/99

CHANGE SHEET

FOR

NSTS 08209 - Space Shuttle
Shuttle Systems Design Criteria
Volume I - Shuttle Performance Assessment Databook

CHANGE NO. 51

Program Requirements Control Board Directive No. S084799AE/(1-1), dated 5/2/01.(1)

May 22, 2001

Robert H. Heselmeyer
Secretary, Program Requirements
Control Board

CHANGE INSTRUCTIONS

1. Remove the following listed pages and replace with the same numbered attached pages:

<u>Page</u>	<u>PRCBD No.</u>
xi	S084799AE
xii	
xxiii - xxviii	S084799AE
xxix - xxx (Add)	S084799AE
2-1	
2-2	S084799AE
4-5	
4-6	S084799AE
4-9	
4-10	S084799AE
4-10A - 4-10B (Add)	S084799AE
4-11	S084799AE
4-12	

4-13	S084799AE
4-14	
4-21 - 4-22	S084799AE
4-27	S084799AE
4-28	
4-29 - 4-40	S084799AE
5-3 - 5-4	S084799AE
5-17 - 5-20	S084799AE
5-21	
5-22 - 5-23	S084799AE
5-24	
5-25	S084799AE
5-25A	
5-27	S084799AE
5-28	
5-29	S084799AE
5-30	
5-31	S084799AE
5-32	
5-33 - 5-34	S084799AE
7-13	S084799AE
7-14	
8-3	
8-4 - 8-7	S084799AE
8-8	
8-9 - 8-19	S084799AE
8-20	
8-41	
8-42	S084799AE
G-113 - G-124 (Add)	S084799AE

NOTE: A black bar in the margin indicates the information that was changed.

- Remove the List of Effective Pages, dated August 31, 2000 and replace with List of Effective Pages, dated May 22, 2001.
- Sign and date this page in the space provided below to show that the changes have been incorporated and file immediately behind the List of Effective Pages.

Signature of person incorporating changes

Date

NSTS 08209 - Space Shuttle
Shuttle Systems Design Criteria
Volume I - Shuttle Performance Assessment Databook

LIST OF EFFECTIVE PAGES

May 22, 2001

The current status of all pages in this document is as shown below:

<u>Page No.</u>	<u>Change No.</u>	<u>PRCBD No.</u>	<u>Date</u>
(i) - (ii)	Rev. B	S052189CF	February 11, 1999
(1) - (2)	Rev. B	S052189CF	February 11, 1999
i - x	Rev. B	S052189CF	February 11, 1999
xi	51	S084799AE	May 2, 2001
xii - xxii	50	S084799AC	May 9, 2000
xxiii - xxx	51	S084799AE	May 2, 2001
1-1	Rev. B	S052189CF	February 11, 1999
1-2 - 1-3	50	S052189DA	April 27, 2000
1-4 - 1-10	Rev. B	S052189CF	February 11, 1999
1-11	50	S052189DA CAR S052189DA	April 27, 2000, May 25, 2000
1-12	Rev. B	S052189CF	February 11, 1999
2-1	Rev. B	S052189CF	February 11, 1999
2-2	51	S084799AE	May 2, 2001
2-3 - 2-8	Rev. B	S052189CF	February 11, 1999
3-1 - 3-2	Rev. B	S052189CF	February 11, 1999
3-3	50	S052189DA	April 27, 2000
3-4 - 3-14	Rev. B	S052189CF	February 11, 1999
3-15	49	S052189CT	August 21, 1999
3-16 - 3-18	Rev. B	S052189CF	February 11, 1999
3-19	50	SSP DOC-455	February 22, 2000
3-20 - 3-22	Rev. B	S052189CF	February 11, 1999
3-23	50	SSP DOC-455	February 22, 2000
3-24 - 3-26	Rev. B	S052189CF	February 11, 1999
3-27	50	SSP DOC-455	February 22, 2000
3-28 - 3-30	Rev. B	S052189CF	February 11, 1999
3-31	50	SSP DOC-455	February 22, 2000
3-32 - 3-54	Rev. B	S052189CF	February 11, 1999
3-55	49	S052189CT	August 21, 1999
3-56 -3-60	Rev. B	S052189CF	February 11, 1999

LIST OF EFFECTIVE PAGES

May 22, 2001

<u>Page No.</u>	<u>Change No.</u>	<u>PRCBD No.</u>	<u>Date</u>
4-1 - 4-2	Rev. B	S052189CF	February 11, 1999
4-3	50	S052189DA	April 27, 2000
4-4 - 4-5	Rev. B	S052189CF	February 11, 1999
4-6	51	S084799AE	May 2, 2001
4-7 - 4-9	Rev. B	S052189CF	February 11, 1999
4-10 - 4-11	51	S084799AE	May 2, 2001
4-12	50	S084799AC	May 9, 2000
4-13	51	S084799AE	May 2, 2001
4-14	50	S084799AC	May 9, 2000
4-15 - 4-19	Rev. B	S052189CF	February 11, 1999
4-20	50	S084799AC	May 9, 2000
4-21 - 4-22	51	S084799AE	May 2, 2001
4-23 - 4-26	Rev. B	S052189CF	February 11, 1999
4-27	51	S084799AE	May 2, 2001
4-28	Rev. B	S052189CF	February 11, 1999
4-29 - 4-40	51	S084799AE	May 2, 2001
5-1 - 5-2	Rev. B	S052189CF	February 11, 1999
5-3 - 5-4	51	S084799AE	May 2, 2001
5-5 - 5-8	Rev. B	S052189CF	February 11, 1999
5-9	48	S071574A	May 3, 1999
5-10 - 5-12	50	S052189DA	April 27, 2000
5-13	Rev. B	S052189CF	February 11, 1999
5-14	50	S052189DA	April 27, 2000
5-15 - 5-16	Rev. B	S052189CF	February 11, 1999
5-17 - 5-20	51	S084799AE	May 2, 2001
5-21	Rev. B	S052189CF	February 11, 1999
5-22 - 5-23	51	S084799AE	May 2, 2001
5-24	Rev. B	S052189CF	February 11, 1999
5-25	51	S084799AE	May 2, 2001
5-25A - 5-26	Rev. B	S052189CF	February 11, 1999
5-27	51	S084799AE	May 2, 2001
5-28	Rev. B	S052189CF	February 11, 1999
5-29	51	S084799AE	May 2, 2001
5-30	Rev. B	S052189CF	February 11, 1999
5-31	51	S084799AE	May 2, 2001
5-32	Rev. B	S052189CF	February 11, 1999

LIST OF EFFECTIVE PAGES

May 22, 2001

<u>Page No.</u>	<u>Change No.</u>	<u>PRCBD No.</u>	<u>Date</u>
5-33 - 5-34	51	S084799AE	May 2, 2001
5-35 - 5-39	50	S084799AC	May 9, 2000
5-40 - 5-71	Rev. B	S052189CF	February 11, 1999
5-72	49	S052189CT	August 21, 1999
5-73 - 5-77	Rev. B	S052189CF	February 11, 1999
5-78 - 5-88	49	S052189CT	August 21, 1999
5-89	Rev. B	S052189CF	February 11, 1999
5-90 - 5-91	49	S052189CT	August 21, 1999
5-92	Rev. B	S052189CF	February 11, 1999
5-93 - 5-94	49	S052189CT	August 21, 1999
5-95 - 5-96	Rev. B	S052189CF	February 11, 1999
5-97	49	S052189CT	August 21, 1999
5-98 - 5-136	Rev. B	S052189CF	February 11, 1999
5-137	49	S052189CT	August 21, 1999
5-138 - 5-139	48	S071574A	May 3, 1999
5-140	Rev. B	S052189CF	February 11, 1999
6-1 - 6-34	Rev. B	S052189CF	February 11, 1999
7-1 - 7-12	Rev. B	S052189CF	February 11, 1999
7-13	51	S084799AE	May 2, 2001
7-14 - 7-66	Rev. B	S052189CF	February 11, 1999
8-1 - 8-3	Rev. B	S052189CF	February 11, 1999
8-4 - 8-7	51	S084799AE	May 2, 2001
8-8	Rev. B	S052189CF	February 11, 1999
8-9 - 8-19	51	S084799AE	May 2, 2001
8-20 - 8-37	50	S084799AC	May 9, 2000
8-38 - 8-41	Rev. B	S052189CF	February 11, 1999
8-42	51	S084799AE	May 2, 2001
8-43 - 8-45	50	S084799AC	May 9, 2000
8-46	Rev. B	S052189CF	February 11, 1999
9-1 - 9-30	Rev. B	S052189CF	February 11, 1999
10-1	50	S052189DA	April 27, 2000
10-2 - 10-7	Rev. B	S052189CF	February 11, 1999
10-8	50	S052189DA	April 27, 2000,
		SSP DOC-455	February 22, 2000
10-9	Rev. B	S052189CF	February 11, 1999
10-10 - 10-11	50	S084799AC	May 9, 2000

LIST OF EFFECTIVE PAGES

May 22, 2001

<u>Page No.</u>	<u>Change No.</u>	<u>PRCBD No.</u>	<u>Date</u>
10-12	50	S052189DA	April 27, 2000
10-13	50	S052189DA S084799AC	April 27, 2000, May 9, 2000
10-14 - 10-32	Rev. B	S052189CF	February 11, 1999
10-33 - 10-35	50	S084799AC	May 9, 2000
10-36 - 10-40	Rev. B	S052189CF	February 11, 1999
A-1 - A-2	Rev. B	S052189CF	February 11, 1999
B-1 - B-2	Rev. B	S052189CF	February 11, 1999
C-1 - C-2	Rev. B	S052189CF	February 11, 1999
C-3	50	S052189DA SSP DOC-455	April 27, 2000, February 22, 2000
C-4 - C-8	Rev. B	S052189CF	February 11, 1999
D-i - D-ii	Rev. B	S052189CF	February 11, 1999
D-iii - iv	49	S052189CT	August 21, 1999
D-1 - D-21	Rev. B	S052189CF	February 11, 1999
D-22 - D-40	49	S052189CT	August 21, 1999
E-1 - E-8	Rev. B	S052189CF	February 11, 1999
F-1 - F-8	Rev. B	S052189CF	February 11, 1999
G-1 - G-88	Rev. B	S052189CF	February 11, 1999
G-89 - G-112	50	S084799AC	May 9, 2000
G-113 - G-124	51	S084799AE	May 2, 2001

**INDEX OF DEVIATIONS/WAIVERS AUTHORIZED FOR REQUIREMENTS
CONTAINED IN THIS DOCUMENT**

<u>Number</u>	<u>Title</u>	<u>Para. No.</u>	<u>Page</u>
1.	Retired per Change Action Request (Reference Level II PRCBD S050741, dated 7/22/89)	7.9 Fig. 7-23	F-5
2.	Retired per Change Action Request (Reference Level II PRCBD S050741A, dated 3/19/90)	7.9 Fig. 7-23	F-5
3.	Retired per Change Action Request (Reference Level II PRCBD S083029R1, dated 6/12/91)	7.9 Fig. 7-23	F-6

THIS PAGE INTENTIONALLY LEFT BLANK

**DEVIATIONS/WAIVERS AUTHORIZED FOR REQUIREMENTS
CONTAINED IN THIS DOCUMENT**

1. **REQUIREMENT:** Retired. (Reference Change Action Request filed with Level II PRCBD S050741, dated 7/22/89.) See Appendix F.
2. **REQUIREMENT:** Retired. (Reference Change Action Request filed with Level II PRCBD S050741A, dated 3/19/90.) See Appendix F.
3. **REQUIREMENT:** Retired. (Reference Change Action Request filed with Level II PRCBD S083029R1, dated 6/12/91.) See Appendix F.

THIS PAGE INTENTIONALLY LEFT BLANK

NSTS 08209
VOLUME I

SPACE SHUTTLE

SHUTTLE SYSTEMS DESIGN CRITERIA
VOLUME I
SHUTTLE PERFORMANCE ASSESSMENT DATABOOK

THIS PAGE INTENTIONALLY LEFT BLANK

FOREWORD

Efficient management of the Space Shuttle Program (SSP) dictates that effective control of program activities be established. Requirements, directives, procedures, interface agreements, and system capabilities shall be documented, baselined, and subsequently controlled by SSP management.

Program requirements controlled by the Manager, Space Shuttle Program, are documented in, attached to, or referenced from Volume I through XVIII of NSTS 07700.

NSTS 08209, Volume I, defines the systems and performance capabilities to be used by all NASA and Contractor organizations for design of Space Shuttle operational trajectories. This volume contains assessment and flight derived performance data, hence it does not necessarily agree with similar data documented in NSTS 07700, Volume X, or in Interface Control Documents (ICDs) or Contract End Item (CEI) specifications. However, data contained in this document provide the basis for the most accurate simulation of vehicle flight characteristics and should be used exclusively for trajectory planning. For missions beyond preliminary planning stages, Trajectory Design Data Packages (TDDPs) are available and should be used for detailed mission analysis. These TDDPs contain precise flight vehicle information as manifested for each mission.

All elements of the SSP must adhere to these baselined requirements. When it is considered by the Space Shuttle program element/project managers to be in the best interest of the SSP to change, waive or deviate from these requirements, an SSP Change Request (CR) shall be submitted to the Program Requirements Control Board (PRCB) Secretary. The CR must include a complete description of the change, waiver or deviation and the rationale to justify its consideration. All such requests will be processed in accordance with NSTS 07700, Volume IV - Book 1 and dispositioned by the Manager, Space Shuttle Program, on a Space Shuttle PRCB Directive (PRCBD).


Tommy W. Holloway
Manager, Space Shuttle Program

THIS PAGE INTENTIONALLY LEFT BLANK

CONTENTS

NSTS 08209, Volume I

1.0	INTRODUCTION	1-1
1.1	SHUTTLE SYSTEMS DESIGN CRITERIA	1-1
1.1.1	Background	1-1
1.1.2	Purpose	1-1
1.1.3	Approach	1-1
1.1.4	Change Authority	1-3
1.1.5	Deviations and Waivers	1-3
1.2	SHUTTLE PERFORMANCE ASSESSMENT DATABOOK (SPAD) ...	1-4
1.2.1	Purpose	1-4
1.2.2	Approach	1-4
1.2.3	Vandenberg Data	1-4
1.2.4	Cross Reference	1-4
2.0	APPLICABLE DOCUMENTS	2-1
2.1	REFERENCE LETTERS	2-4
3.0	VEHICLE CONFIGURATION	3-1
3.1	SPACE SHUTTLE VEHICLE	3-1
3.2	ORBITER VEHICLE	3-1
3.3	EXTERNAL TANK	3-2
3.3.1	ET Propellant Slosh Model	3-3
3.4	SOLID ROCKET BOOSTER (SRB)	3-15
3.5	SHUTTLE COORDINATE SYSTEMS AND DIMENSIONS	3-16
4.0	MASS PROPERTIES AND PROPELLANT LOADING	4-1
4.1	ELEMENT INERT WEIGHTS	4-1
4.2	CREW COMPARTMENT	4-1
4.3	WEIGHT ALLOWANCE FOR ICE	4-1
4.4	PROPELLANT LOADING	4-1
4.4.1	Main Propulsion System (MPS)	4-1
4.4.2	Orbital Maneuvering System (OMS)	4-4
4.4.3	Reaction Control System (RCS)	4-4
5.0	PROPULSION PERFORMANCE	5-1
5.1	MAIN PROPULSION SYSTEM	5-1

CONTENTS

NSTS 08209, Volume I

5.2	ORBITAL MANEUVERING SYSTEM	5-4
5.3	REACTION CONTROL SYSTEM	5-5
5.4	REUSABLE SOLID ROCKET MOTOR (RSRM)	5-8
5.4.1	Description of FModel6 RSRM Steady-state and Tail-off Thrust Model	5-11
5.4.2	Description of Low-pressure RSRM Tail-off Thrust Model	5-12
5.5	BOOSTER SEPARATION MOTOR (BSM)	5-13
6.0	FLIGHT CONTROL EFFECTORS	6-1
6.1	SSME GIMBAL	6-1
6.2	OMS GIMBAL	6-2
6.3	SRB GIMBAL	6-2
6.4	ORBITER ELEVONS	6-3
7.0	TRAJECTORY AND PERFORMANCE ASSESSMENT	7-1
7.1	MISSION PROFILE	7-2
7.1.1	Ascent Trajectory	7-3
7.1.2	Descent Trajectory	7-8
7.2	LAUNCH SITE LOCATION AND VEHICLE ORIENTATION	7-8
7.3	LAUNCH WINDOW	7-8
7.4	ASCENT/ABORT PERFORMANCE	7-9
7.4.1	Performance Adjustments	7-13
7.5	TRAJECTORY SHAPING	7-14
7.6	(DELETED)	7-15
7.7	(DELETED)	7-15
7.8	(DELETED)	7-15
7.9	(DELETED)	7-15
7.10	SSME PITCH AND YAW PARALLEL	7-15
7.11	MECO TARGETS	7-15
7.12	ET SEPARATION	7-16
7.13	POST-MECO THROUGH ORBIT INSERTION	7-18

CONTENTS

NSTS 08209, Volume I

7.14	ASCENT PROPELLANT MANAGEMENT	7-20
7.15	REFERENCE MISSION PERFORMANCE TRACKING	7-22
	7.15.1 Mission 1	7-23
	7.15.2 Mission 9	7-23
7.16	(DELETED)	7-23
7.17	I-LOAD SELECTION	7-23
7.18	MINIMUM ORBITER LIFT-OFF WEIGHT	7-24
8.0	FLIGHT PERFORMANCE RESERVE (FPR)	8-1
8.1	ANALYTICAL FPR	8-1
8.2	FPR COMPUTATION	8-4
8.3	(DELETED)	8-7
9.0	SOFTWARE	9-1
9.1	ELEVON LOAD RELIEF	9-1
9.2	ADAPTIVE GUIDANCE THROTTLING (AGT)	9-2
9.3	SEQUENCING	9-4
10.0	ASCENT SIMULATION MATH MODELS	10-1
10.1	ATMOSPHERE	10-1
10.2	WINDS	10-1
10.3	EARTH GEOMETRY	10-1
10.4	LAUNCH AND LANDING SITES	10-2
10.5	EARTH GRAVITY	10-2
10.6	AERODYNAMICS	10-8
10.7	MASS PROPERTIES	10-8
	10.7.1 Mass Properties - MECO Command Through MPS Dump	10-9
10.8	PROPULSION	10-12
10.9	ASCENT GN&C	10-13
10.10	NONRIGID BODY EFFECTS	10-14
	10.10.1 Elevon Aeroelastic Deformation	10-14

CONTENTS

NSTS 08209, Volume I

10.10.2 Thrust Structure Deformation Effects on SSME Gimbal Angles	10-16
10.10.3 Effect of Crew Module Deformation on AAs and IMU	10-17
10.10.4 Second Stage Crew Vibration Analysis	10-18
10.11 SRB TAIL-OFF PITCH MOMENT	10-18

APPENDICES

NSTS 08209, Volume I

A	(DELETED)	A-1
B	(DELETED)	B-1
C	ACRONYMS, SYMBOLS AND ABBREVIATIONS	C-1
D	HISTORIC SRM PERFORMANCE DATA	D-i
E	MEANS AND STANDARD DEVIATION VERSUS JULIAN DAY FOR 30-DAY AVERAGE AMBIENT TEMPERATURE (DEG F), KSC	E-1
F	RETIRED DEVIATIONS/WAIVERS	F-1
G	HISTORICAL MPS PROPELLANT INVENTORY DATA	G-1

TABLES

NSTS 08209, Volume I

1.1	RELOCATION OF NSTS 07700, VOLUME X - BOOK 2 (APPENDIX 10.12) PARAGRAPHS INTO NSTS 08209, VOLUME I	1-5
1.2	NSTS 08209, VOLUME I SUPPORT MATRIX	1-7
3.1	SHUTTLE COORDINATE SYSTEM TRANSFORMATIONS	3-17
3.3.1.2.1	EXTERNAL LIGHTWEIGHT TANK LO ₂ SLOSH PARAMETER TABLE	3-19
3.3.1.2.2	EXTERNAL LIGHTWEIGHT TANK LH ₂ SLOSH PARAMETER TABLE	3-23
3.3.1.2.3	EXTERNAL SUPER LIGHTWEIGHT TANK LO ₂ SLOSH PARAMETER TABLE	3-27
3.3.1.2.4	EXTERNAL SUPER LIGHTWEIGHT TANK LH ₂ SLOSH PARAMETER TABLE	3-31
3.3.1.3.1	FOUR BAFFLE LO ₂ DAMPING TABLE	3-35
3.3.1.3.2	LWT LH ₂ DAMPING TABLE	3-36
3.3.1.3.3	THREE BAFFLE LO ₂ DAMPING TABLE	3-37
3.3.1.3.4	SLWT LH ₂ DAMPING TABLE	3-38
3.3.1.5.1	ET LH ₂ DEPLETION SEQUENCE (INCLUDES PRESSURANT)	3-39
3.3.1.5.2	ET LO ₂ DEPLETION SEQUENCE (INCLUDES PRESSURANT)	3-43
4.1	BASELINE PROPELLANT INVENTORIES - NOMINAL	4-5
4.1.1	PROPELLANT INVENTORY REVISIONS VERSUS STS FLIGHTS	4-7
4.1.2	DAY-OF-LAUNCH MARGINS PROGRAM INPUTS (LWT)	4-11
4.1.3	DAY-OF-LAUNCH MARGINS PROGRAM INPUTS (SLWT)	4-13
4.1.4	LWT TANKING TABLE DATA, LWT-68 AND SUBS	4-15
4.1.5	SLWT TANKING TABLE DATA, SLWT-01 AND SUBS	4-16
4.1.6	LO ₂ ULLAGE PRESSURE REDUCTION EQUATIONS, CURVE FIT COEFFICIENTS	4-17
4.1.7	VENTED AND PRESSURIZED LH ₂ PROPELLANT BULK CONDITIONS VERSUS GH ₂ ULLAGE PRESSURE	4-18
4.1.8	VENTED AND PRESSURIZED LO ₂ PROPELLANT BULK CONDITIONS VERSUS GO ₂ ULLAGE PRESSURE	4-19
4.1.9	PLOAD PROGRAM INPUTS, LWT AND SLWT	4-20

TABLES

NSTS 08209, Volume I

4.1.10	ORBITER MPS PROPELLANT DUMP PERFORMANCE SUMMARY (NO-FAIL TRAJECTORY)	4-23
4.1.11	ORBITER MPS PROPELLANT DUMP PERFORMANCE SUMMARY (AOA/ATO TRAJECTORY, ONE ENGINE OUT)	4-24
4.1.12	ORBITER MPS PROPELLANT DUMP PERFORMANCE SUMMARY (TAL TRAJECTORY, ONE ENGINE OUT)	4-25
4.1.13	ORBITER MPS PROPELLANT DUMP PERFORMANCE SUMMARY (RTLS TRAJECTORY, ONE ENGINE OUT)	4-26
4.2	THRU 4.127 – (RELOCATED TO NEW APPENDIX G)	4-27
4.128	STS-GEN R0103L MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)	4-29
4.129	STS-GEN R0103L MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)	4-30
4.130	STS-GEN R0103L MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	4-31
4.131	STS-GEN R0103L MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	4-32
4.132	STS-GEN R0103L MPS PROPELLANT INVENTORY INPUT SHEET (RTLS)	4-33
4.133	STS-GEN R0103L MPS PROPELLANT INVENTORY LOAD SHEET (RTLS)	4-34
4.134	STS-GEN R0104S MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)	4-35
4.135	STS-GEN R0104S MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)	4-36
4.136	STS-GEN R0104S MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	4-37
4.137	STS-GEN R0104S MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	4-38
4.138	STS-GEN R0104S MPS PROPELLANT INVENTORY INPUT SHEET (RTLS)	4-39
4.139	STS-GEN R0104S MPS PROPELLANT INVENTORY LOAD SHEET (RTLS)	4-40
5.1	SSME OPERATIONAL CHARACTERISTICS	5-15

TABLES

NSTS 08209, Volume I

5.2	(DELETED)	5-16
5.2.1	SSME START TRANSIENT PREDICTIONS FOR ALL THREE ENGINES .	5-17
5.2.2	SSME START TRANSIENT PREDICTION VERSUS TIME, INDIVIDUAL SSMEs	5-18
5.3	SSME SHUTDOWN TRANSIENT PREDICTION FOR EACH ENGINE	5-20
5.4	(DELETED)	5-21
5.4.1	SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM MPL (65% RPL) AND 67% RPL	5-22
5.4.2	SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM 91% RPL .	5-24
5.4.2.1	(DELETED)	5-25A
5.4.3	SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM RPL	5-26
5.4.4	SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM NPL (104% RPL)	5-28
5.4.5	SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM FPL (109% RPL)	5-30
5.5	(DELETED)	5-32
5.5.1	STANDARD MPS ASSESSMENT TAGS, BLOCK II/IIA SSMEs	5-33
5.5.2	(DELETED)	5-35
5.5.3	(DELETED)	5-37
5.5.4	(DELETED)	5-39
5.5.5	(DELETED)	5-40
5.5.6	(DELETED)	5-41
5.5.7	(DELETED)	5-42
5.5.8	(DELETED)	5-43
5.5.9	(DELETED)	5-44
5.5.10	(DELETED)	5-45
5.5.11	(DELETED)	5-46
5.5.12	(DELETED)	5-47
5.5.13	(DELETED)	5-48
5.5.14	(DELETED)	5-49

TABLES

NSTS 08209, Volume I

5.5.15	(DELETED)	5-50
5.5.16	(DELETED)	5-51
5.5.17	(DELETED)	5-52
5.5.18	(DELETED)	5-53
5.5.19	(DELETED)	5-54
5.5.20	(DELETED)	5-55
5.5.21	(DELETED)	5-56
5.5.22	(DELETED)	5-57
5.5.23	(DELETED)	5-58
5.5.24	(DELETED)	5-59
5.5.25	(DELETED)	5-60
5.5.26	(DELETED)	5-61
5.5.27	(DELETED)	5-62
5.5.28	(DELETED)	5-63
5.6	ORBITAL MANEUVERING SYSTEM PERFORMANCE DATA	5-64
5.7	PRIMARY RCS THRUSTER NOMINAL STEADY-STATE THRUST CORRECTION FACTOR AND PROPELLANT FLOW AS A FUNCTION OF NUMBER OF THRUSTERS OPERATING	5-66
5.8	VERNIER THRUSTER NOMINAL STEADY-STATE THRUST CORRECTION FACTOR AND PROPELLANT FLOW AS A FUNCTION OF NUMBER OF THRUSTERS OPERATING	5-67
5.9	NOMINAL RCS THRUST COMPONENTS AND APPLICATION LOCATIONS	5-68
5.10	MR AND SPECIFIC IMPULSE (Isp) FOR VARIOUS RCS USAGE MODES	5-70
5.11	PROPELLANT CHARACTERISTICS	5-71
5.12	SRB NOZZLE CHARACTERISTICS	5-72
5.13	SRB + 3-SIGMA TOLERANCE REQUIREMENTS	5-73
5.14	RSRM PREDICTED PMBT BASED ON 33-YEAR MEAN OF 30-DAY AVERAGE	5-74
5.15	(DELETED)	5-75

TABLES

NSTS 08209, Volume I

5.16	SRB MOTOR PERFORMANCE AT ANY PMBT	5-76
5.17	(RESERVED)	5-77
5.18	PREDICTED PERFORMANCE TIME HISTORY (60° F) FOR RSRM (TP-R074-99)	5-78
5.19	RSRM NOMINAL THRUST-TIME LIMITS (VACUUM - 60° F) (TP-R074-99)	5-83
5.20	RSRM BLOCK MOTOR THRUST ADJUSTMENT INCREMENTS	5-87
5.21	(DELETED)	5-88
5.22	(DELETED)	5-89
5.22.1	RSRM BLOCK MOTOR PREDICTIONS PERFORMANCE SUMMARY, PMBT = 70° F	5-90
5.22.2	(DELETED)	5-91
5.23	(DELETED)	5-92
5.23.1	(DELETED)	5-93
5.23.2	ADJUSTED RSRM BLOCK MOTOR PREDICTIONS PERFORMANCE SUMMARY, PMBT = 70° F T - DELAY I-LOAD = 4.42 SEC LIGHTWEIGHT CASE	5-94
5.24	BLOCK MOTOR PREDICTIONS PERFORMANCE MODIFICATION EQUATIONS	5-95
5.25	RSRM MEAN TAIL-OFF THRUST AND SHAPE FACTORS	5-98
6.1	ACTUATOR/EFFECTOR PARAMETERS OF TVC EFFECTOR SYSTEMS	6-5
6.2	COMBINATIONS OF GIMBAL ANGLES FOR SSME-1 AND 2 THAT RESULT IN ZERO CLEARANCE BETWEEN NOZZLES (JUST TOUCHING)	6-6
6.3	COMBINATIONS OF GIMBAL ANGLES FOR SSME-1 AND 3 THAT RESULT IN ZERO CLEARANCE BETWEEN NOZZLES (JUST TOUCHING)	6-7
6.4	COMBINATIONS OF GIMBAL ANGLES FOR SSME-2 AND 3 THAT RESULT IN ZERO CLEARANCE BETWEEN NOZZLES (JUST TOUCHING)	6-8
6.5	CLEARANCES BETWEEN NOZZLES OF SSME-1 AND OMS ENGINES (CASE 3)	6-9

TABLES

NSTS 08209, Volume I

6.6	CLEARANCES BETWEEN NOZZLES OF SSME-1 AND OMS ENGINES (CASE 4)	6-10
6.7	CLEARANCES BETWEEN NOZZLES OF SSME-1 AND OMS ENGINES (CASE 5)	6-11
7.1	LOCATION OF SPACE SHUTTLE LAUNCH SITES	7-25
7.2	(DELETED)	7-26
7.3	(DELETED)	7-27
7.4	ETR - TARGETS	7-28
7.5	(DELETED)	7-29
7.6	(DELETED)	7-30
7.7	(DELETED)	7-31
7.8	DIRECT INSERTION OMS TARGETS FOR 28.45 TO 57-DEGREE INCLINATION (APOGEE \leq 250 NM)	7-32
7.9	(DELETED)	7-33
7.10	(DELETED)	7-34
7.11	(DELETED)	7-35
7.12	SPACE SHUTTLE/SPACE STATION REFERENCE MISSION PERFORMANCE DESCRIPTION	7-36
8.1	SYSTEM DISPERSIONS FOR FPR COMPUTATION	8-9
8.2	EFFECT OF 3σ CLASS 1 (6:1) DISPERSIONS ON PROPELLANT (lb _m) REQUIRED TO REACH MECO	8-11
8.3	PROCESSED CLASS 1 (6:1) PROPELLANT CONSUMPTION DISPERSIONS (lb _m)	8-12
8.4	CLASS 2 (NON 6:1) DISPERSIONS AND AUXILIARY DATA FOR FPR COMPUTATION	8-13
8.5	NORMAL TRAJECTORY FPR FOR NOMINAL DOL (LWT AND SLWT)	8-14
8.6	PTA TRAJECTORY FPR FOR NOMINAL DOL (LWT AND SLWT)	8-15
8.7	RTLs TRAJECTORY FPR FOR NOMINAL DOL (LWT AND SLWT)	8-16
8.8	NORMAL TRAJECTORY FPR WITHOUT PLOAD (LWT AND SLWT)	8-17

TABLES

NSTS 08209, Volume I

8.9	PTA TRAJECTORY FPR WITHOUT PLOAD (LWT AND SLWT)	8-18
8.10	RTLS TRAJECTORY FPR WITHOUT PLOAD (LWT AND SLWT)	8-19
8.11	(DELETED)	8-20
8.12	(DELETED)	8-21
8.13	(DELETED)	8-22
8.14	(DELETED)	8-23
8.15	(DELETED)	8-24
8.16	(DELETED)	8-25
8.17	(DELETED)	8-26
8.18	(DELETED)	8-27
8.19	(DELETED)	8-28
8.20	(DELETED)	8-29
8.21	(DELETED)	8-30
8.22	(DELETED)	8-31
8.23	(DELETED)	8-32
8.24	(DELETED)	8-33
8.25	(DELETED)	8-34
8.26	(DELETED)	8-35
8.27	(DELETED)	8-36
8.28	(DELETED)	8-37
9.1	ELEVON ACTUATOR GEOMETRY	9-7
9.2	ELEVON HINGE MOMENT DATA	9-8
9.3	ELEVON LOAD RELIEF DRIVE AND RETURN SETTINGS	9-9
9.4	ELEVON LOAD RELIEF I-LOADS	9-10
9.5	ELEVON LOAD RELIEF LOGIC	9-11
9.6	OVERVIEW OF DAP EVENTS/SEQUENCING	9-12
9.7	SRB SEPARATION SEQUENCE EVENTS	9-17

TABLES

NSTS 08209, Volume I

9.8	ET SEPARATION SEQUENCE OF EVENTS	9-19
9.9	(DELETED)	9-22
9.10	(DELETED)	9-23
9.11	(DELETED)	9-24
10.1	(DELETED)	10-21
10.2	EARTH GEOMETRY AND ROTATION CONSTRAINTS	10-22
10.3	RUNWAY SUMMARY FOR ETR LAUNCHES TO 28.45-DEGREE INCLINATION (a) OPS-3 AREAS	10-23
10.4	RUNWAY SUMMARY FOR ETR LAUNCHES TO 57-DEGREE INCLINATION (a) OPS-3 AREAS	10-25
10.5	(DELETED)	10-27
10.6	RUNWAY DATA	10-28
10.7	EARTH GRAVITY CONSTANTS	10-30
10.8	TYPICAL BUOYANCY AND VENTED VOLUME EFFECTS	10-31
10.9	(DELETED)	10-32
10.9.1	BLOCK II/IIA SSMEs INFLUENCE COEFFICIENTS	10-33
10.9.2	(DELETED)	10-34
10.9.3	(DELETED)	10-35
10.10	SSME DEFLECTIONS DUE TO ELASTIC STRUCTURAL DEFLECTION .	10-36
10.11	SRB TAIL-OFF PITCH MOMENT	10-37
D.1	PREDICTED PERFORMANCE TIME HISTORY (60° F) FOR 1980 DESIGN POINT SRB HPM (MSFC 112-80)	D-1
D.1.1	PREDICTED PERFORMANCE TIME HISTORY (60° F) FOR SRB HPM (TC-271-84)	D-9
D.2	HPM SRB NOMINAL THRUST-TIME LIMITS (VACUUM - 60° F) (TC-271-84)	D-13
D.3	BLOCK II MOTOR THRUST ADJUSTMENT INCREMENTS	D-17
D.4	BLOCK II MOTOR PREDICTION DESIGNATION	D-18
D.5	BLOCK II MOTOR PREDICTIONS PERFORMANCE SUMMARY, PMBT = 70° F	D-19

TABLES

NSTS 08209, Volume I

D.5.1	BLOCK II SRB FILAMENT WOUND CASE PERFORMANCE SUMMARY, PMBT = 56° F	D-20
D.6	BLOCK MODEL COMPUTER FILE IDENTIFICATION	D-21
G.4.2	STS-26 MPS PROPELLANT INVENTORY INPUT SHEET (NOMINAL) ...	G-5
G.4.3	STS-26 MPS PROPELLANT INVENTORY LOAD SHEET (NOMINAL)	G-6
G.4.4	STS-26 MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-7
G.4.5	STS-26 MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-8
G.4.6	STS-26 MPS PROPELLANT INVENTORY INPUT SHEET (RTL)S)	G-9
G.4.7	STS-26 MPS PROPELLANT INVENTORY LOAD SHEET (RTL)S)	G-10
G.4.8	STS-GEN MPS PROPELLANT INVENTORY INPUT SHEET (NOMINAL) .	G-11
G.4.9	STS-GEN MPS PROPELLANT INVENTORY LOAD SHEET (NOMINAL) ..	G-12
G.4.10	STS-GEN MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL) ..	G-13
G.4.11	STS-GEN MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL) ..	G-14
G.4.12	STS-GEN MPS PROPELLANT INVENTORY INPUT SHEET (RTL)S)	G-15
G.4.13	STS-GEN MPS PROPELLANT INVENTORY LOAD SHEET (RTL)S)	G-16
G.4.14	STS-GEN MPS PROPELLANT INVENTORY INPUT SHEET (NOMINAL) .	G-17
G.4.15	STS-GEN MPS PROPELLANT INVENTORY LOAD SHEET (NOMINAL) ..	G-18
G.4.16	STS-GEN MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL) ..	G-19
G.4.17	STS-GEN MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL) ..	G-20
G.4.18	STS-GEN MPS PROPELLANT INVENTORY INPUT SHEET (RTL)S)	G-21
G.4.19	STS-GEN MPS PROPELLANT INVENTORY LOAD SHEET (RTL)S)	G-22
G.4.20	STS-GEN BB MPS PROPELLANT INVENTORY INPUT SHEET (NOMINAL)	G-23
G.4.21	STS-GEN BB MPS PROPELLANT INVENTORY LOAD SHEET (NOMINAL)	G-24
G.4.22	STS-GEN BB MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-25
G.4.23	STS-GEN BB MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-26
G.4.24	STS-GEN BB MPS PROPELLANT INVENTORY INPUT SHEET (RTL)S) ..	G-27

TABLES

NSTS 08209, Volume I

G.4.25	STS-GEN BB MPS PROPELLANT INVENTORY LOAD SHEET (RTL5) ..	G-28
G.4.26	STS-GEN CC MPS PROPELLANT INVENTORY INPUT SHEET (NOMINAL)	G-29
G.4.27	STS-GEN CC MPS PROPELLANT INVENTORY LOAD SHEET (NOMINAL)	G-30
G.4.28	STS-GEN CC MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-31
G.4.29	STS-GEN CC MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-32
G.4.30	STS-GEN CC MPS PROPELLANT INVENTORY INPUT SHEET (RTL5) ..	G-33
G.4.31	STS-GEN CC MPS PROPELLANT INVENTORY LOAD SHEET (RTL5) ..	G-34
G.4.32	STS-GEN DD MPS PROPELLANT INVENTORY INPUT SHEET (NOMINAL)	G-35
G.4.33	STS-GEN DD MPS PROPELLANT INVENTORY LOAD SHEET (NOMINAL)	G-36
G.4.34	STS-GEN DD MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-37
G.4.35	STS-GEN DD MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-38
G.4.36	STS-GEN DD MPS PROPELLANT INVENTORY INPUT SHEET (RTL5) ..	G-39
G.4.37	STS-GEN DD MPS PROPELLANT INVENTORY LOAD SHEET (RTL5) ..	G-40
G.4.38	STS-GEN EE MPS PROPELLANT INVENTORY INPUT SHEET (NOMINAL)	G-41
G.4.39	STS-GEN EE MPS PROPELLANT INVENTORY LOAD SHEET (NOMINAL)	G-42
G.4.40	STS-GEN EE MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-43
G.4.41	STS-GEN EE MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-44
G.4.42	STS-GEN EE MPS PROPELLANT INVENTORY INPUT SHEET (RTL5) ..	G-45
G.4.43	STS-GEN EE MPS PROPELLANT INVENTORY LOAD SHEET (RTL5) ..	G-46
G.4.44	STS-GEN R9501 MPS PROPELLANT INVENTORY INPUT SHEET (NOMINAL)	G-47

TABLES

NSTS 08209, Volume I

G.4.45	STS-GEN R9501 MPS PROPELLANT INVENTORY LOAD SHEET (NOMINAL)	G-48
G.4.46	STS-GEN R9501 MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-49
G.4.47	STS-GEN R9501 MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-50
G.4.48	STS-GEN R9501 MPS PROPELLANT INVENTORY INPUT SHEET (RTLS)	G-51
G.4.49	STS-GEN R9501 MPS PROPELLANT INVENTORY LOAD SHEET (RTLS)	G-52
G.4.50	STS-GEN R9601L MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)	G-53
G.4.51	STS-GEN R9601L MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)	G-54
G.4.52	STS-GEN R9601L MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-55
G.4.53	STS-GEN R9601L MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-56
G.4.54	STS-GEN R9601L MPS PROPELLANT INVENTORY INPUT SHEET (RTLS)	G-57
G.4.55	STS-GEN R9601L MPS PROPELLANT INVENTORY LOAD SHEET (RTLS)	G-58
G.4.56	STS-GEN R9602S MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)	G-59
G.4.57	STS-GEN R9602S MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)	G-60
G.4.58	STS-GEN R9602S MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-61
G.4.59	STS-GEN R9602S MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-62
G.4.60	STS-GEN R9602S MPS PROPELLANT INVENTORY INPUT SHEET (RTLS)	G-63
G.4.61	STS-GEN R9602S MPS PROPELLANT INVENTORY LOAD SHEET (RTLS)	G-64

TABLES

NSTS 08209, Volume I

G.4.62	STS-GEN R9603S MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)	G-65
G.4.63	STS-GEN R9603S MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)	G-66
G.4.64	STS-GEN R9603S MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-67
G.4.65	STS-GEN R9603S MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-68
G.4.66	STS-GEN R9603S MPS PROPELLANT INVENTORY INPUT SHEET (RTL5)	G-69
G.4.67	STS-GEN R9603S MPS PROPELLANT INVENTORY LOAD SHEET (RTL5)	G-70
G.4.74	STS-GEN R9605L MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)	G-71
G.4.75	STS-GEN R9605L MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)	G-72
G.4.76	STS-GEN R9605L MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-73
G.4.77	STS-GEN R9605L MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-74
G.4.78	STS-GEN R9605L MPS PROPELLANT INVENTORY INPUT SHEET (RTL5)	G-75
G.4.79	STS-GEN R9605L MPS PROPELLANT INVENTORY LOAD SHEET (RTL5)	G-76
G.4.80	STS-GEN R9701L MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)	G-77
G.4.81	STS-GEN R9701L MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)	G-78
G.4.82	STS-GEN R9701L MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-79
G.4.83	STS-GEN R9701L MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-80
G.4.84	STS-GEN R9701L MPS PROPELLANT INVENTORY INPUT SHEET (RTL5)	G-81

TABLES

NSTS 08209, Volume I

G.4.85	STS-GEN R9701L MPS PROPELLANT INVENTORY LOAD SHEET (RTL)S)	G-82
G.4.86	STS-GEN R9702L MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)	G-83
G.4.87	STS-GEN R9702L MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)	G-84
G.4.88	STS-GEN R9702L MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-85
G.4.89	STS-GEN R9702L MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-86
G.4.90	STS-GEN R9702L MPS PROPELLANT INVENTORY INPUT SHEET (RTL)S)	G-87
G.4.91	STS-GEN R9702L MPS PROPELLANT INVENTORY LOAD SHEET (RTL)S)	G-88
G.4.92	STS-GEN R9801L MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)	G-89
G.4.93	STS-GEN R9801L MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)	G-90
G.4.94	STS-GEN R9801L MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-91
G.4.95	STS-GEN R9801L MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-92
G.4.96	STS-GEN R9801L MPS PROPELLANT INVENTORY INPUT SHEET (RTL)S)	G-93
G.4.97	STS-GEN R9801L MPS PROPELLANT INVENTORY LOAD SHEET (RTL)S)	G-94
G.4.98	STS-GEN R9802L MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)	G-95
G.4.99	STS-GEN R9802L MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)	G-96
G.4.100	STS-GEN R9802L MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-97
G.4.101	STS-GEN R9802L MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-98

TABLES

NSTS 08209, Volume I

G.4.102	STS-GEN R9802L MPS PROPELLANT INVENTORY INPUT SHEET (RTLS)	G-99
G.4.103	STS-GEN R9802L MPS PROPELLANT INVENTORY LOAD SHEET (RTLS)	G-100
G.4.104	STS-GEN R9805S MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)	G-101
G.4.105	STS-GEN R9805S MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)	G-102
G.4.106	STS-GEN R9805S MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-103
G.4.107	STS-GEN R9805S MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-104
G.4.108	STS-GEN R9805S MPS PROPELLANT INVENTORY INPUT SHEET (RTLS)	G-105
G.4.109	STS-GEN R9805S MPS PROPELLANT INVENTORY LOAD SHEET (RTLS)	G-106
G.4.110	STS-GEN R9806S MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)	G-107
G.4.111	STS-GEN R9806S MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)	G-108
G.4.112	STS-GEN R9806S MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-109
G.4.113	STS-GEN R9806S MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-110
G.4.114	STS-GEN R9806S MPS PROPELLANT INVENTORY INPUT SHEET (RTLS)	G-111
G.4.115	STS-GEN R9806S MPS PROPELLANT INVENTORY LOAD SHEET (RTLS)	G-112
G.4.116	STS-GEN R0003L MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)	G-113
G.4.117	STS-GEN R0003L MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)	G-114
G.4.118	STS-GEN R0003L MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-115

TABLES

NSTS 08209, Volume I

G.4.119	STS-GEN R0003L MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-116
G.4.120	STS-GEN R0003L MPS PROPELLANT INVENTORY INPUT SHEET (RTLS)	G-117
G.4.121	STS-GEN R0003L MPS PROPELLANT INVENTORY LOAD SHEET (RTLS)	G-118
G.4.122	STS-GEN R0004S MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)	G-119
G.4.123	STS-GEN R0004S MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)	G-120
G.4.124	STS-GEN R0004S MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)	G-121
G.4.125	STS-GEN R0004S MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)	G-122
G.4.126	STS-GEN R0004S MPS PROPELLANT INVENTORY INPUT SHEET (RTLS)	G-123
G.4.127	STS-GEN R0004S MPS PROPELLANT INVENTORY LOAD SHEET (RTLS)	G-124

FIGURES

NSTS 08209, Volume I

1-1	ORGANIZATION AND DATA RELATIONSHIPS IN NSTS 08209	1-11
3-1	SPACE SHUTTLE VEHICLE	3-47
3-2	ORBITER VEHICLE DIMENSIONS	3-48
3-3	EXTERNAL TANK	3-49
3.3.1.3-1	THREE AND FOUR BAFFLE LO ₂ DAMPING CURVES	3-50
3.3.1.3-2	LWT AND SLWT LH ₂ DAMPING CURVES	3-51
3.3.1.4-1	SLOSH MODEL: SPRING–MASS–DAMPER ANALOGY	3-52
3.3.1.4-2	COORDINATE SYSTEM FOR SLOSH EQUATION DERIVATION	3-53
3.3.1.4-3	LIQUID OXYGEN AND HYDROGEN SLOSH CONFIGURATION	3-54
3-4	SOLID ROCKET BOOSTER	3-55
3-5	SHUTTLE COORDINATE SYSTEM	3-56
3-6	SPACE SHUTTLE VEHICLE DIMENSIONS	3-57
3-7	SHUTTLE SYSTEM DYNAMIC BODY AXES	3-58
3-8	AERODYNAMIC BODY-AXIS REFERENCE SYSTEM	3-59
5-1	MAIN PROPULSION SUBSYSTEM	5-101
5-2	MAIN PROPULSION SUBSYSTEM SCHEMATIC	5-102
5-3	SPACE SHUTTLE MAIN ENGINE	5-103
5-4	(DELETED)	5-104
5-5	(DELETED)	5-105
5-5-1	BSM THRUST PROFILE AT 30° PMBT	5-106
5-5-2	BSM THRUST PROFILE AT 70° PMBT	5-107
5-5-3	BSM THRUST PROFILE AT 100° PMBT	5-108
5-5-4	BSM THRUST PROFILE AT 110° PMBT	5-109
5-5-5	BSM THRUST PROFILE AT 120° PMBT	5-110
5-5-6	BSM THRUST PROFILE AT 100° F (WITH 10% MARGIN)	5-111
5-5-7	BSM THRUST PROFILE AT 110° F (WITH 10% MARGIN)	5-112
5-6	(DELETED)	5-113
5-7	(DELETED)	5-114

FIGURES

NSTS 08209, Volume I

5-8	(DELETED)	5-115
5-9	(DELETED)	5-116
5-10	(DELETED)	5-117
5-11	(DELETED)	5-118
5-12	(DELETED)	5-119
5-13	(DELETED)	5-120
5-14	EIGHT-SECOND SSME SHUTDOWN THRUST	5-121
5-15	ORBITAL MANEUVER SUBSYSTEM	5-122
5-16	ORBITAL MANEUVER SUBSYSTEM SCHEMATIC	5-123
5-17	OMS ENGINE CHAMBER PRESSURE AND THRUST START TRANSIENT	5-124
5-18	OMS ENGINE CHAMBER PRESSURE AND THRUST SHUTDOWN TRANSIENT	5-125
5-19	THRUST VECTOR MISALIGNMENT	5-126
5-20	REACTION CONTROL SUBSYSTEM	5-127
5-21	RCS SCHEMATICS	5-128
5-22	RCS THRUSTER IDENTIFICATION	5-129
5-23	THRUST CORRECTION FACTOR FOR ALTITUDE (C_A) PRIMARY THRUSTERS	5-130
5-24	NOMINAL VACUUM THRUST SUMMARY	5-131
5-25	SRB SOLID ROCKET MOTOR	5-134
5-26	GEOMETRIC THRUST VECTOR	5-135
5-27	DYNAMIC THRUST VECTOR	5-136
5-28	RSRM NOMINAL PERFORMANCE REQUIREMENTS (VACUUM, 60° F PMBT)	5-137
5-29	IGNITION THRUST IMBALANCE	5-138
5-30	IGNITION MODEL MAXIMUM/MINIMUM PRESSURE RISE RATE ENVELOPE	5-139
6-1	FCS EFFECTORS	6-13
6-2	SSME/SRB GIMBAL DEFLECTION SIGN CONVENTIONS	6-14

FIGURES

NSTS 08209, Volume I

6-3	MPS ENGINE ACTUATOR ORIENTATION - VIEW LOOKING FORWARD	6-15
6-4	NOMINAL SSME AND ACTUATOR GEOMETRY	6-16
6-5	MAIN ENGINE GIMBAL PITCH AXIS	6-17
6-6	MAIN ENGINE GIMBAL YAW AXIS	6-18
6-7	RATE CAPABILITY VERSUS EXTERNAL LOAD OF THE MPS I ACTUATOR SUBSYSTEM	6-19
6-8	RATE CAPABILITY VERSUS EXTERNAL LOAD OF THE MPS TYPE II AND II ACTUATION SUBSYSTEM	6-20
6-9	CLEARANCES BETWEEN SSME-1, SSME-2 (D_{12}), AND SSME-3 (D_{13}) AS A FUNCTION OF SSME-1 GIMBAL ANGLES, δ_{y1} AND δ_{p2} , WITH SSME-2 AND 3 HELD IN THEIR NULL POSITIONS	6-21
6-10	CLEARANCES BETWEEN SSME-2, SSME-1 (D_{12}), AND SSME-3 (D_{23}) AS A FUNCTION OF SSME-2 GIMBAL ANGLES, δ_{y2} AND δ_{p2} , WITH SSME-1 AND 3 HELD IN THEIR NULL POSITIONS	6-22
6-11	GIMBAL ENVELOPE OF SSME-1 WITH SOFTWARE LIMITS TO PREVENT INTERFERENCE BETWEEN SSME-1 AND OMS PODS ...	6-23
6-12	REGIONS OF POTENTIAL COLLISION BETWEEN NOZZLES OF SSME-1 AND LEFT AND RIGHT OMS ENGINES	6-24
6-13	CLEARANCE BETWEEN LOWER SSME AND BODY FLAP AS A FUNCTION OF PITCH GIMBAL ANGLE (δ) FOR LOWER SSME AND BODY FLAP DEFLECTION (δ_{BF})	6-25
6-14	OMS GIMBAL YAW/PITCH AND NULL ANGLES	6-26
6-15	SRB ACTUATOR ORIENTATION - VIEW LOOKING FORWARD	6-27
6-16	SRM NOZZLE DEFLECTION	6-28
6-17	SRB NOZZLE RATE CAPABILITY VERSUS NOZZLE TORQUE FOR LOW, NOMINAL, AND HIGH PERFORMANCE RESPONSES	6-29
6-18	SRB TVC GIMBAL ROCK AND TILT COMMAND LIMITS	6-30
6-19	ELEVON NUMBERING AND SIGN CONVENTION	6-31
6-20	ELEVON ACTUATOR GEOMETRY	6-32
6-21	MAXIMUM ELEVON DEFLECTIONS	6-33
7-1	ASCENT TRAJECTORY MAJOR SHAPING CONSTRAINTS	7-37

FIGURES

NSTS 08209, Volume I

7-2	TRAJECTORY DESIGN/FLIGHT CONSTRAINTS	7-38
7-3	MAXIMUM DYNAMIC PRESSURE LIMITING (A)	7-39
7-4	AERODYNAMIC LOADS LIMITING (B)	7-40
7-5	AERODYNAMIC HEATING LIMITING (C)	7-41
7-6	ACCELERATION LIMITING (D)	7-42
7-7	SHAPING FOR INTACT ABORT (E)	7-43
7-8	MECO TARGETING FOR ET DISPOSAL (F)	7-44
7-9	LIFT-OFF LOADS LIMITING (G)	7-45
7-10	PROPULSION SYSTEM CONSTRAINT (G)	7-46
7-11	TYPICAL MISSION PROFILE	7-47
7-12	TYPICAL ASCENT AND DESCENT TRAJECTORY PROFILES	7-48
7-13	SPACE SHUTTLE ABORT CHARACTERISTICS	7-49
7-14	(DELETED)	7-50
7-15	ABORT MODE AVAILABILITY VS. ENGINE OUT TIME FOR TYPICAL 51.6-INCLINATION MISSION	7-51
7-16	OMS CAPABILITY EXAMPLES	7-52
7-17	TYPICAL RTLS PROFILE	7-53
7-18	LAUNCH HOLD CAPABILITY	7-54
7-19	(DELETED)	7-55
7-20	(DELETED)	7-56
7-21	(DELETED)	7-57
7-22	(DELETED)	7-58
7-23	(DELETED)	7-59
7-24	ETR 28.450 DIRECT INSERTION MECO TARGET LINES	7-60
7-25	ETR 57.0-DEGREE INCLINATION DI TARGET LINES	7-61
7-26	NOMINAL INTEGRATED DUMP TIMELINE	7-62
7-27	RTLS ABORT INTEGRATED DUMP TIMELINE	7-63
7-28	TAL ABORT INTEGRATED DUMP TIMELINE	7-64
7-29	ATO ABORT INTEGRATED DUMP TIMELINE	7-65

FIGURES

NSTS 08209, Volume I

8-1	STEPS IN FPR CALCULATION	8-39
8-2	PROCESSING UNSYMMETRICAL PARAMETERS BY A PARABOLIC FIT	8-40
8-3	PROCESSING UNSYMMETRICAL PARAMETERS BY A BILINEAR FIT	8-41
8-4	FPR AND FPR+BIAS CURVES FOR NORMAL TRAJECTORY (3σ) (LWT AND SLWT)	8-42
8-5	(DELETED)	8-43
8-6	(DELETED)	8-44
8-7	(DELETED)	8-45
9-1	FLIGHT CONTROL PHASES AND MAJOR EVENTS DURING FIRST-STAGE ASCENT	9-25
9-2	ACTIVE ELEVON HINGE MOMENT LOAD RELIEF	9-26
9-3	PROFILE OF MISSION PHASE, FLIGHT CONTROL DESIGNATION, AND MM PROGRAM NUMBERS	9-27
9-4	MM TRANSITIONS	9-28
9-5	ASC_DAP AND GC_STEER SUBPHASES, NOMINAL MISSION	9-29
9-6	ASC_DAP AND GC_STEER SUBPHASES, RTLS ABORT	9-30
10-1	CREW MODULE SLOPE MODEL	10-38
10-2	SRB TAIL-OFF PITCH MOMENT	10-39
10-3	PREDICTED CREW VIBRATION AS A FUNCTION OF PAYLOAD CG	10-40
D-1	HPM SRB NOMINAL PERFORMANCE REQUIREMENTS (VACUUM, 60° F PMBT)	D-23

THIS PAGE INTENTIONALLY LEFT BLANK

I

1.0 INTRODUCTION

This section provides the necessary background information, general context, and purpose for NSTS 08209. It defines the organization of the document into volumes and the general relationship of the volumes. Further, it defines the general purpose, content, and application of each volume.

1.1 SHUTTLE SYSTEMS DESIGN CRITERIA

1.1.1 Background

NSTS 08209, Shuttle Systems Design Criteria, was conceived to provide a single source for system description, performance, and design characteristics that have an influence on mission trajectory design. It evolved because of the need for a more comprehensive and detailed treatment of these areas than was provided by NSTS 07700, Volume X - Book 2 (Appendix 10.12), Flight and Ground System Specification, Environment Design, Weight and Performance, and Avionics Events. This reference material was deleted from NSTS 07700 by direction of the Manager, Space Shuttle Program, after the Shuttle transitioned from the developmental to the operational phase, at which time the general need and plan for this document were defined.

1.1.2 Purpose

The basic purpose of NSTS 08209 is to provide a document that can be used as a source book for trajectory design that makes available, in a convenient format, information on all performance, constraint and dispersion characteristics that influence or limit trajectory design, and that defines systems analysis methods and models used in developing analytical products for trajectory design. As such, it is intended to provide a central information source for system characteristics and considerations that can influence the design of trajectories for particular missions. In this capacity, NSTS 08209 will define, directly or by reference, all data, models, and methods that may be necessary to satisfy its intended purpose (including basic descriptions and performance information, certification analyses, dispersions, and design constraints and trajectory criteria).

1.1.3 Approach

Because of the complexity and multidisciplinary nature of the subject matter, NSTS 08209 has been structured as a multi-volume set. In this plan, existing volumes have been designated as follows:

Volume I - Shuttle Performance Assessment Databook

Volume II - Integrated Vehicle Baseline Characterization (IVBC-3)

- Volume III - Systems and Environmental Dispersions
- Volume IV - Generic Ascent Flight Design Requirements (formerly Design Criteria and Constraints)
- Volume V - Critical Math Model Document (Replaced by the Critical Math Model Database [CMMD])
- Volume VI - Retired per Program Requirements Control Board Directive (PRCBD) S052189BB
- Volume VII - Performance Enhancement Systems Certification Summary Document

Volumes II and VII are historical information documents. All other volumes are requirements documents. Together, these volumes satisfy the general purpose defined in Paragraph 1.1.2. It is intended that the documents be maintained in a current state throughout the life of the Shuttle Program.

Figure 1-1 illustrates the basic scope of the individual documents, their relationship to one another, and the general purpose served by the information contained therein, in the analytical process leading to effective trajectory design. The simplified flow diagram in Figure 1-1 shows the generation of nominal trajectory ranges and limits to satisfy the defined requirements for any specific mission, the inclusion of dispersion effects to provide the necessary performance margins and confidence, and the verification of dispersed trajectories against limiting design constraints to establish the nominal design trajectory for the mission. In each step of this general process, the significant contributing volume of NSTS 08209 is indicated. Volume II contributes only as background for the establishment of design criteria in Volume IV.

Volume I provides brief technical descriptions of components of the overall Shuttle System and its component subsystems, serves as a source book for basic performance data, and identifies and defines significant models and analytical techniques for performance assessment and design.

Volume II traces the history of IVBC-3 analyses and relates it to current performance data. In doing so, it provides an overview of the analytical methods that are applicable to the design of mission trajectories and identifies major considerations affecting those trajectories.

Volume III provides an identification and quantification of significant dispersions and provides the analytical techniques for applying them to trajectory design.

Volume IV formerly titled, Design Criteria and Constraints, was completely rewritten to add missing requirements and remove obsolete data and retitled Generic Ascent Flight Design Requirements Document. It identifies and defines significant system constraints on ascent trajectory design and provides analytical interpretations of them in terms of derived ascent trajectory design criteria.

Volume V has been replaced by the CMMD. The CMMD is a web accessible database for documenting the configuration-controlled mathematical models identified by the program as critical in defining and evaluating the integrated Space Shuttle Vehicle (SSV). Critical Math Models (CMMs) have been baselined and approved for use in Space Shuttle mission and hardware design and certification, as well as Commit-to-Flight (CTF), Day-of-Launch (DOL), and post-flight analyses. Model characteristics, program usage, certification processes, limitations, and assumptions are published in the CMMD, as are names of personnel accountable for control and maintenance of the CMMs, computer system residences of the models, computer identification numbers, and appropriate references for more detailed explanation and application.

Volume VI retired per PRCBD S052189BB.

Volume VII provides a description of the integration tasks required to certify the Space Shuttle System with the defined performance enhancement modifications put in place to support the Space Station flights.

1.1.4 Change Authority

Change authority for this document has been delegated by the Program Requirements Control Board (PRCB) to the Integration Control Board (ICB) and the Ascent Flight Systems Integration Group (AFSIG). Changes to this document must be submitted on a Space Shuttle Program (SSP) Change Request (CR) form, per procedures outlined in NSTS 07700, Volume IV, Configuration Management Requirements. The AFSIG shall serve as the preliminary SSP review forum for changes and shall make recommendations to the ICB as to their final disposition. Formal review and dispositioning of changes shall be accomplished at the ICB. Changes not unanimously agreed upon within the SSP community or the affect program costs or schedules shall be forwarded by the ICB to the PRCB for dispositioning in accordance with procedures in NSTS 07700, Volume IV.

Per NSTS 07700, Volume IV, Configuration Management Requirements, all applicable SSP elements and technical managers shall provide support for verifying the data contained in the above documents, except the historical Volumes II and VII. To assist in meeting this requirement, a support matrix (Table 1.2) has been developed for this volume. The matrix identifies the groups responsible for ensuring the accuracy of each section.

1.1.5 Deviations and Waivers

Material contained in the documents comprising the Shuttle Systems Design Criteria is to be used as the basis for trajectory design for specific SSV missions. For some missions, special considerations may warrant the generation of deviations or waivers

relative to individual criteria. Such deviations or waivers will only be authorized if analysis shows there will be no significant compromising of safety or recoverability. Approval authority for deviations and waivers will reside with the Space Shuttle PRCB.

1.2 SHUTTLE PERFORMANCE ASSESSMENT DATABOOK (SPAD)

1.2.1 Purpose

Volume I of the Shuttle Systems Design Criteria is a handbook of assessment and flight-derived performance data used for the design and analysis of ascent trajectories for the operational Space Shuttle launch vehicle. This document contains requirements for use in Space Shuttle assessment and flight design.

1.2.2 Approach

The data and descriptions contained in the SPAD are based on the current operational capabilities of the Space Shuttle System, which are either as-built or flight-derived capabilities.

In the event of conflicting statements regarding systems capabilities for ascent trajectory design between this and any other SSP document, the data in this document shall take precedence. However, if a program directive (a Trajectory Design Data Package [TDDP] is considered a program directive) has been subsequently issued by the Manager, Space Shuttle Program, which affects the statement(s) in question, the program directive shall take precedence. Such conflicting data should be brought to the attention of the AFSIG so the conflict can be eliminated, if possible.

1.2.3 Vandenberg Data

Vandenberg Launch Site data required for historical retention purposes is located in NSTS 08209, Volume II. This data is principally related to the IVBC-3 Certification assessment.

1.2.4 Cross Reference

The paragraphs from NSTS 07700, Volume X - Book 2 (Appendix 10.12), which have been incorporated into this document are identified in Table 1.1.

TABLE 1.1**RELOCATION OF NSTS 07700, VOLUME X - BOOK 2 (APPENDIX 10.12)
PARAGRAPHS INTO NSTS 08209, VOLUME I**

Volume X - Book 2 (Appendix 10.12) Paragraph	Subject	NSTS 08209, Volume I Paragraph
4.0	System and Element Performance Design Criteria	Foreword, 1.2.4
4.1	Shuttle Configuration	3.0
4.2.4	OMS/RCS Usage for Aborts	7.14
4.2.8	Maximum Nominal Dynamic Pressure	*
4.2.10	Coast Time After MECO	7.13
4.2.15	Nominal Performance	7.4
4.2.16	Commanded Alpha and Elevon Schedules	*
4.2.17	SRB Staging Time	7.8b, 9.3
4.2.18	Weight Allowance for Ice	4.3
4.2.20	Nominal Performance Basis	7.2
4.2.20.1	WTR Launch Site	7.2
4.2.20.2	ETR Launch Site	7.2
4.2.21	ET Separation Time	7.12, 9.3
4.2.23	Ascent Constraints and Limitations	Section 5.0, 7.0
4.3	SSME Weight and Performance Characteristics	4.4.1, 5.1
4.3.2	Internal Propellants	4.4.1
4.3.3	Performance Characteristics	5.1
4.3.4.1	Second Stage Gimbaling for One Engine Out	7.10
4.3.5	SSME Throttling	7.7
4.3.5.1	SSME Throttling for RTLS	7.7
4.4.3.2	Specific Impulse	5.3
4.4.3.3	Propellant Loading	4.4.3

*See NSTS 08209, Volume IV

TABLE 1.1**RELOCATION OF NSTS 07700, VOLUME X - BOOK 2 (APPENDIX 10.12)
PARAGRAPHS INTO NSTS 08209, VOLUME I - Concluded**

Volume X - Book 2 (Appendix 10.12) Paragraph	Subject	NSTS 08209, Volume I Paragraph
4.4.4.3	Crossfeed Capability	5.2
4.4.4.4	Specific Impulse	5.2
4.4.4.5	Position for AOA	5.2
4.4.4.6	Loading Requirements	4.4.2
4.4.4.6.1	OMS/RCS Interconnect	5.2
4.4.4.6.2	Impulse Requirements	5.2
4.4.5.1	Propellants in Feedline at MECO	4.4.1
4.4.5.2	Propellant Dump	7.14
4.4.7	Personnel Chargeable Items	4.2
4.5	ET Weight and Performance Characteristics	4.0, 4.1
4.6.3	SRB Groundrules for Trajectory Performance	5.4, 7.4, 7.5
4.7.3	MPS Propellants	4.4.1

TABLE 1.2

NSTS 08209, VOLUME I SUPPORT MATRIX

Para. No.	Supporting Element(s)								Supporting Tech Area(s)							
	Integ.	SRB	RSRM	SSME	ET	Orbiter	L&L	MOD	Abort	Aero	Asc. Perf.	GN&C	Load/Stru	Nat. Envir.	Propulsion	Thermal
3.0	X															
3.1	X															
3.2						X				X					X	
3.3					X								X		X	
3.3.1	X				X						X					
3.3.1.1	X				X						X					
3.3.1.2	X				X						X					
3.3.1.3	X				X						X					
3.3.1.4	X				X						X					
3.3.1.4.1	X				X						X					
3.3.1.4.2	X				X						X					
3.3.1.4.3	X				X						X					
3.3.1.4.4	X				X						X					
3.3.1.4.5	X				X						X					
3.3.1.5	X				X						X					
3.4		X									X		X			
3.5	X									X						
4.0	X															
4.1	X										X					
4.2	X															
4.3	X										X					
4.4																
4.4.1	X				X	X					X				X	
4.4.2	X					X									X	
4.4.3	X					X									X	
5.0																
5.1	X			X	X										X	
5.2						X									X	
5.3						X										
5.4	X		X								X	X			X	
5.4.1	X		X								X	X			X	
5.4.2	X		X								X	X			X	
5.5	X	X									X	X			X	

TABLE 1.2

NSTS 08209, VOLUME I SUPPORT MATRIX - Continued

Para. No.	Supporting Element(s)								Supporting Tech Area(s)							
	Integ.	SRB	RSRM	SSME	ET	Orbiter	L&L	MOD	Abort	Aero	Asc. Perf.	GN&C	Load/Stru	Nat. Envir.	Propulsion	Thermal
6.0		X				X						X				
6.1	X											X				
6.2						X						X				
6.3		X										X				
6.4						X						X				
7.0	X							X								
7.1	X															
7.1.1	X															
7.1.1.1	X							X	X							
7.1.1.1.1	X							X	X							
7.1.1.1.2	X							X	X		X					
7.1.1.1.3	X							X	X							
7.1.1.1.4	X							X	X							
7.1.2								X								
7.2	X						X				X					
7.3	X							X			X					
7.4	X							X	X		X					
7.4.1	X										X					
7.4.1.1	X										X					
7.4.1.2	X				X						X				X	
7.5	X							X			X	X				
7.6 (Deleted)																
7.7 (Deleted)																
7.8 (Deleted)																
7.9 (Deleted)																
7.10	X											X				
7.11	X							X								
7.12	X							X				X				
7.13	X							X	X			X				
7.14	X					X		X	X			X			X	
7.15	X										X					
7.15.1	X										X					
7.15.2	X										X					

TABLE 1.2

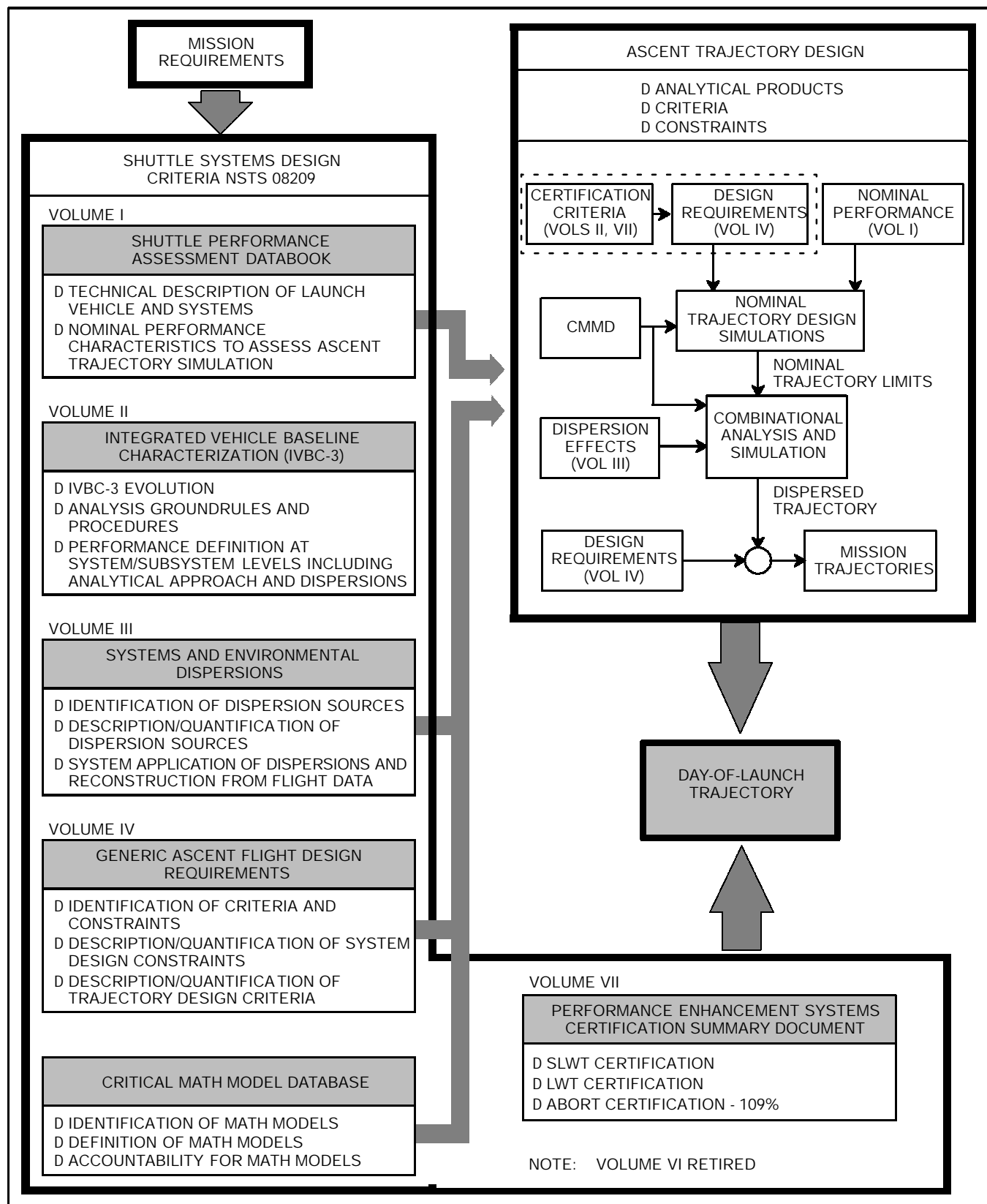
NSTS 08209, VOLUME I SUPPORT MATRIX – Concluded

Para. No.	Supporting Element(s)								Supporting Tech Area(s)							
	Integ.	SRB	RSRM	SSME	ET	Orbiter	L&L	MOD	Abort	Aero	Asc. Perf.	GN&C	Load/Stru	Nat. Envir.	Propulsion	Thermal
7.15.2.1 (Deleted)																
7.15.2.2 (Deleted)																
7.16 (Deleted)																
7.17	X							X			X					
8.0	X										X				X	
8.1	X										X					
8.2	X	X			X						X				X	
8.3 (Deleted)																
9.0	X										X					
9.1	X					X					X	X				
9.2	X										X					
9.3	X										X					
10.0	X									X	X	X	X	X	X	
10.1	X													X		
10.2	X													X		
10.3	X															
10.4	X						X	X						X		
10.5	X													X		
10.6	X					X				X						
10.7	X				X						X	X				
10.7.1	X			X							X				X	
10.8	X			X											X	
10.9	X										X					
10.10	X															
10.10.1	X					X				X						
10.10.2	X									X						
10.10.3	X									X						
10.10.4	X									X						
10.11	X									X		X				

THIS PAGE INTENTIONALLY LEFT BLANK

FIGURE 1-1

ORGANIZATION AND DATA RELATIONSHIPS IN NSTS 08209



THIS PAGE INTENTIONALLY LEFT BLANK

2.0 APPLICABLE DOCUMENTS

The following documents are applicable to the requirements contained in this document. "(Current Issue)" is shown in place of the specific date and issue when the document is under Space Shuttle PRCB control. The current status of documents shown with "(Current Issue)" may be determined from NSTS 08102, Program Document Description and Status Report.

NSTS 07700 Volume III (Current Issue)	Flight Definition and Requirements Directive Ref. Para. 7.4.1.3, 7.17
NSTS 07700 Volume IV (Current Issue)	Configuration Management Requirements Ref. Foreword, Para. 1.1.4
NSTS 07700 Volume X (Current Issue)	Flight and Ground System Specification Ref. Para. 5.4.1, 7.0, 7.12, 9.3, Table 8.1
NSTS 07700 Volume X - Book 1 (Current Issue)	Flight and Ground System Specification, Requirements Ref. Para. 5.4, 5.4.1, 5.5, 7.0, 7.1.1.1, 7.15, 7.18, Figure 6-16
NSTS 07700 Volume X - Book 2 (Current Issue)	Flight and Ground System Specification, Environment Design, Weight and Performance, and Avionics Events Ref. Para. 1.1.1, 1.2.4, 7.18, 10.2, Table 1.1

NSTS 08209
Volume II
(Current Issue)

Shuttle Systems Design Criteria, Integrated Vehicle
Baseline Characterization (IVBC-3)

Ref. Para. 1.1.3, 1.1.4, 1.2.3, 7.0, Figure 1-1

NSTS 08209
Volume III
(Current Issue)

Shuttle Systems Design Criteria, Systems and
Environmental Dispersions

Ref. Para. 1.1.3, 7.0, 8.2, Figure 1-1

NSTS 08209
Volume IV
(Current Issue)

Shuttle Systems Design Criteria, Generic Ascent
Flight Design Requirements

Ref. Para. 1.1.3, 6.4, 7.0, 7.4, 7.5, 7.10, 7.11, 7.12,
Figure 1-1

NSTS 08209
Volume VI
(Retired)

Shuttle Systems Design Criteria, Day-of-Launch
I-Load Update (DOLILU) Technical Requirements

Ref. Para. 1.1.3, Figure 1-1

NSTS 08209
Volumes VII
(Current Issue)

Shuttle Systems Design Criteria, Performance
Enhancement Systems Certification Summary
Document

Ref. Para. 1.1.3, 1.1.4, 7.0, Figure 1-1

NSTS 08934

Space Shuttle Operational Databook

Ref. Para. 5.1, 5.2, 5.3, 5.4, 9.3, 10.7

NSTS 08934 Volume II	Space Shuttle Operational Databook, Mission Mass Properties Ref. Para. 4.0, 4.4.2, 4.4.3, 10.7
NSTS 08934 Volume V	Space Shuttle Operational Databook, Orbiter Flight Capability Ref. Para. 7.1.2
NSTS 08934 Volume VI	Space Shuttle Operational Databook, Orbiter Propellant Dump Reference Data Ref. Para 7.14, 9.3
NSTS 09095	Space Shuttle Systems Weight and Performance Status Report Ref. Para. 4.0, 4.1, 4.2, 4.4.2, 4.4.3, 10.7
NSTS 21075	Space Shuttle Operational Flight Design Standard Groundrules and Constraints Ref. Para. 7.0, 7.1.2, 7.4, 7.11, 7.17
NASA SP-106 1979	The Dynamic Behavior of Liquids in Moving Containers Ref. Para. 3.3.1.2
SS-P-002-510	Space Shuttle Computer Programs Development Specifications (CPDS) Ref. Table 9.8

TMX-58153
October 1974
(Formerly JSC 09084)

Coordinate Systems for the Space Shuttle
Program

Ref. Para. 3.5

ICD 13M15000

Space Shuttle Orbiter Vehicle/Main Engine Inter-
face Control Document

Ref. Para. 5.1, 8.2

2.1 REFERENCE LETTERS

NASA-MSFC
Letter EL24
(84-7)

Agreement on LO₂ Tank Ullage Pressure and
LO₂ Bulk Density Relationship to be used for
the Space Shuttle Flights STS-11 through
STS-22

Ref. Para. 4.4.1

NASA-MSFC
Letter SA31 (211-97)
April 14, 1997

Lockheed Martin Manned Space Systems (LMSS)
Update to Mass Properties, Non-Propulsive
Consumables

Ref. Para. 10.7

Rocketdyne
IL 155-ES-83-13
January 21, 1984

Shutdown Transient Predictions for the FPL Type
Engines

Ref. Para. 4.4.1

IL 283-200-85-CG-063
October 25, 1985

Updated Data Base of Ascent Flight Control
Effector Systems

Ref. Para. 6.0

IL 287-104-84-004
January 4, 1984

MPS Vaporized Propellant Pressurization
Masses for Propellant Inventory

Ref. Para. 4.4.1

IL 287-104-84-016 February 9, 1984	Documentation of a Propellant Bulk Density Computer Program for use in Space Shuttle Propellant Loading Applications Ref. Para. 4.4.1
IL FSD&P/MAI-80-822 October 30, 1980	Deterministic Reserve Ref. Para. 8.2
IL FSD&P/MAI-80-354 August 19, 1980	ARD FPR Briefing for the Ascent Flight Techniques Panel Ref. Para. 8.2
IL FSD&P/MAI-80-351 August 12, 1980	Propellant Reserve for Inflight Margin Prediction by the ARD Ref. Para. 8.2
IL FSD&P/MAI-80-350 August 12, 1980	Documentation of Ascent Flight Performance Reserve Methods Ref. Para. 8.2
IL FSD&P/MAI-80-157 April 16, 1980	FPR Probability Comparison Ref. Para. 8.2
STS83-0002	Space Shuttle Orbiter Operational Level C Functional Subsystem Software Requirements Document - Ascent/RTLS Guidance Ref. Para. 9.0, 10.9
STS83-0005	Space Shuttle Orbiter Operational Level C Functional Subsystem Software Requirements Document Ascent/RTLS Navigation Ref. Para. 9.0, 10.5, 10.9

STS83-0008 Volumes I & II	Space Shuttle Orbiter Operational Level C Functional Subsystem Software Requirements Document - Ascent and Transition DAP
	Ref. Para. 9.0, 10.9
STS83-0010	Space Shuttle Orbiter Operational Level C Functional Subsystem Software Requirements Document - Redundancy Management
	Ref. Para. 9.0, 10.9
STS83-0016	Space Shuttle Orbiter Operational Level C Functional Subsystem Software Requirements Document - Effector SOP
	Ref. Para. 9.0, 10.9
STS83-0016	Space Shuttle Orbiter Operational Level C Functional Subsystem Software Requirements Document - Sensor/Controller SOP
	Ref. Para. 10.9
STS83-0026	Space Shuttle Orbiter Operational Level C Functional Subsystem Software Requirements Document - Sequencing
	Ref. Para. 9.0, 10.9
STS85-0118 Volumes I - V	Operational Aerodynamic Design Data Book
	Ref. Para. 10.6, 10.10.1
SSD92D0673	GN&C Data Book
	Ref. Para. 10.9

AFSIG Presentation
November 17, 1997

Lockheed Martin Manned Space Systems
(LMMSS) Briefing - ET Non-Propulsive
Consumables Flow Rate Update

Ref. Para. 10.7

AIAA Paper No.
88-0164
January 11, 1988

Space Shuttle Flight Software Design
Consideration for Solid Rocket Booster
Separation

Ref. Para. 9.0

THIS PAGE INTENTIONALLY LEFT BLANK

3.0 VEHICLE CONFIGURATION

3.1 SPACE SHUTTLE VEHICLE

The Space Shuttle flight system depicted in Figure 3-1 consists of an Orbiter with Space Shuttle Main Engines (SSMEs), an External Tank (ET), and two Solid Rocket Boosters (SRBs). The Orbiter with SSMEs and the SRB are reusable elements; the ET is expended on each launch.

The SSMEs, used during ascent, obtain their propellants from the ET. The Orbital Maneuvering System (OMS) and Reaction Control System (RCS) engines provide for maneuvering and attitude control during space flight. The OMS engines can also be used on ascent to provide additional performance capability. Aerodynamic surfaces on the wings and vertical stabilizer control the Orbiter during entry phase of atmospheric flight.

The SRBs burn in parallel with the SSMEs and are separated from the Orbiter/ET at an altitude of approximately 150,000 feet. The SRBs descend on parachutes and land in the ocean about 150 Nautical Miles (NM) from the launch site. They are recovered by ships, returned to land, refurbished, and then reused.

3.2 ORBITER VEHICLE

The Orbiter Vehicle contains the crew and payload for the Space Shuttle Vehicle system and was designed to satisfy the following payload/mission requirements:

- a. Payload maximum size of 15 feet in diameter by 60 feet in length and 65,000 pounds.
- b. Provisions for the payload (protection, support, and handling).
- c. Maximum acceleration of 3 g's.
- d. Provisions for mission duration of seven days.
- e. Provisions for orbital maneuvers, attitude control, etc.
- f. Land like an airplane.
- g. Provide redundant subsystems for high probability of mission success.
- h. Provide for refurbishment and reflight.

As shown in Figure 3-2, the Orbiter is comparable in size and weight to modern transport aircraft. It has an inert weight of approximately 172,000 pounds (including SSME), a length of 121.52 feet, and a wing span of 78.06 feet.

The Main Propulsion System (MPS) used during launch consists of three Rocket Engines (SSMEs), the ET, plumbing, and controls. Among the Orbiter controls are the

LO₂ Engine Cutoff (ECO) sensors that monitor for propellant depletion. All of the propellant is contained in the ET, which is jettisoned prior to orbit injection.

The OMS is contained in two external pods on the aft fuselage. These units provide thrust for orbit change, rendezvous, deorbit, and ascent (if required). The RCS is contained in the two OMS pods and in a module in the nose section of the forward fuselage. These units provide attitude control in space and precision velocity changes for the final phases of rendezvous and docking or orbit modification. In addition, the RCS, in conjunction with the Orbiter's aerodynamic control surfaces, provides attitude control during entry.

The Orbiter Vehicle is trimmed to provide a hypersonic lift-to-drag ratio of approximately 1.3 during entry. At subsonic speed, the maximum trimmed lift-to-drag ratio, with the speed brake closed, is about 4.9. The maximum design touch-down speed of the Orbiter is 225 knots.

3.3 EXTERNAL TANK

The ET, illustrated in Figure 3-3, supplies the Orbiter Main Propulsion System with Liquid Hydrogen (LH₂) and Liquid Oxygen (LO₂) at prescribed pressures, temperatures, and flow rates. Both the LH₂ and LO₂ tanks are equipped with vent and relief valves to permit loading, pressurization, and relief functions. Tank level sensors provide for propellant loading and the LH₂ SSME shutdown signals. The ET is thermally protected with a nominal 1-inch-thick Spray-on Foam Insulation (SOFI), employing additional SOFI and a charring ablator to withstand localized high heating. Since the ET is an expendable element, the ET subsystems are designed for single usage to minimize costs.

The ET reacts the SRB thrust through its intertank structure and provides attach structure to the Orbiter to react the SSME thrust. At lift-off, the ET contains approximately 1.6 million pounds of usable propellant. After Main Engine Cutoff (MECO), the ET is separated from the Orbiter before orbital velocity is achieved. The ET then proceeds on a ballistic reentry path and breaks up prior to impact in the ocean.

The ET consists of a forward LO₂ tank, an unpressurized intertank, and an LH₂ tank. The LO₂ tank is an aluminum alloy monocoque structure composed of a fusion-welded assembly of preformed, chem-milled gores, panels, machined fittings, and ring chords. The tank contains anti-slosh and anti-vortex baffles. A 17-inch diameter feedline conveys propellant through the intertank and externally aft to the ET/Orbiter disconnect. The tank's double wedge nose cone reduces drag and heating and serves as a lightning rod.

The intertank is a semimonocoque cylindrical structure with flanges on each end for joining the LO₂ and LH₂ tanks. The intertank contains the SRB thrust beam and fittings

which distribute SRB loads to the LO₂ and LH₂ tanks. The intertank houses ET instrumentation components, and provides an umbilical plate which interfaces with a ground facility arm. The umbilical plate accommodates purge gas supply, hazardous gas detection, and hydrogen gas boil off during ground operations. The intertank consists of mechanically joined skin, stringers, and machined panels of aluminum alloy. The intertank is vented in flight.

The LH₂ tank is a semimonocoque structure composed of fusion-welded barrel sections, five beam ring frames, and forward and aft ellipsoidal domes. The tank contains an antivortex baffle and a siphon outlet to transmit propellant to the ET/Orbiter disconnect. Structural loads are transferred via the forward attach strut, two ET/Orbiter aft attach fittings, the thrust distribution structure, the aft SRB/ET stabilizing strut attachments, and the aft ET/SRB attach fittings.

3.3.1 ET Propellant Slosh Model

The slosh model consists of the original ET tanking table, slosh model parameters, damping, slosh Equations of Motion (EOM), and propellant mass tables. This slosh model is only applicable during the powered flight phase, that is, the positive Axial Acceleration (AX). The high level model descriptions, model ownership, authorized use, and references for each model are provided in the CMMD. The detail model description, implementation mechanization, and input tables are provided herein. The following subsections describe the details of each model and data.

3.3.1.1 LO₂/LH₂ Tanking Tables

Tanking tables provide the relationship between propellant loading level and the volume of propellant contained in each tank. Both LO₂ and LH₂ tank tables are provided at cryogenic conditions with pressurized and vented cases for, Lightweight Tank (LWT) and Super Lightweight Tank (SLWT) at various tanking conditions and models. Tank wall deflections are modeled using ullage pressure, full loading levels, propellant density and cryogenic shrinking effects. For LWT, these deflections were obtained by using the BOSOR model. SLWT deflections were obtained by using the NASTRAN model. Propellant volumes have been used to define propellant inventories and the amount of propellant loaded on DOL. Each LO₂ and LH₂ tank fill data are tabulated in terms of surface height in ET x-coordinates, surface height from the bottom, tank radius at the surface height, liquid volume and liquid X Center-of-Gravity (CG) in ET coordinates at every one inch of surface height. The tanking tables include the ullage pressure, density, and temperature.

It is noted that both LO₂ and LH₂ tank tables include the liquid in the feedline. The majority of the LH₂ tank feedline is inside of the tank, while all the LO₂ feedline is outside of the tank. For the LO₂, the bottom of the LWT and SLWT is 963.4 inches in ET

coordinates. These tanking tables are used for the slosh model parameter calculations in the next section.

3.3.1.2 LO₂/LH₂ Slosh Model Parameters

Three tank fill table parameters including volume, surface height, and radius from the original tanking table are used to compute three slosh model parameters, namely, slosh mass, the slosh CG location from the surface along x-axis, and slosh frequency factor (lambda).

It is noted that both tank tables include the liquid in the feedline. However, since the slosh parameter equation uses only the liquid mass in the tank, the mass in the feedline should be taken out. No slosh dynamics is assumed in the feedline. For the LO₂ tank, the bottom of the tank is 963.425 inches in ET coordinates. The nearest surface station of 1-inch increment (Station 963.44179) was chosen to define the bottom of the tank, instead of using the interpolation, since the mass difference would be negligible. Thus, the volume and height tables were adjusted by subtracting the feedline mass at the bottom of the LO₂ tank before use, that is, to subtract 1113.0 inches and 164.69777 cu-ft of height and volume, respectively, from their values in the tank. For the LH₂ tank, because most of the LH₂ feedline is inside of the tank, the fill parameters are inclusive of feedline volume. The impact of LH₂ mass in the feedline is considered insignificant since the weight and volume of LH₂ are small. Therefore, an adjustment of LH₂ feedline weight is not necessary. The liquid X CG parameter in ET coordinates is not used and is for reference only.

Three slosh model parameters such as slosh mass, slosh X CG from surface, and slosh frequency factor (lambda) are computed using the original tank fill parameters. These slosh model parameters are computed by using the equivalent cylinder slosh model in the reference document (NASA SP-106, The Dynamic Behavior of Liquids in Moving Containers, 1979). Using the equations for spring-mass from the reference, the slosh mass, CG location from the surface, and sloshing frequency factor are computed as below:

$$H_e = V * 12^3 / (\pi * R^2)$$

$$M_s = 0.4545 * (M_t) * (R/H_e) * \text{TANH}(1.84 * H_e/R)$$

$$H_s = 1.086 * R * \text{TANH}(0.9205 * H_e/R)$$

$$\text{Lambda} = \text{SQRT}(1.841 * \text{TANH}(1.841 * H_e/R))$$

where, V = liquid volume in tank from tank table (ft³)

R = surface radius from tank table (in)

H_e = equivalent surface height of radius, R in cylinder (in)

M_t = total liquid mass in the tank (slugs)

Ms = slosh mass (slugs)
Hs = slosh mass CG location from liquid surface (in)
Ax = vehicle axial acceleration (fps²)
Lambda = slosh frequency factor
TANH = hyperbolic tangent function

There are two sets of lambda's generated and tabulated in the separate columns of the tables. One is for Flight Control System (FCS) usage to compute the stability margins, and the other is for Guidance, Navigation and Control (GN&C) 6-Degrees of Freedom (DOF) simulation. The reason to have a separate lambda is to keep the FCS stability independent of rigid body dynamics. The slosh frequency is tailored in the bottom of the ellipsoidal section to match the rigid body dynamics so that flight path angle better matches with the flight data. However, this modification (so called hybrid model) results in a less conservative FCS stability margin near MECO. Therefore, the unmodified lambda using the equivalent cylinder model is used for FCS stability assessment.

Lambda for FCS Stability Assessment

The lambda for the FCS stability analysis is provided in separate columns of Tables 3.3.1.2.1 and 3.3.1.2.2 for LWT and Tables 3.3.1.2.3 and 3.3.1.2.4 for SLWT. These lambda's are generated using the equivalent cylinder model for all sections of the appropriate tank.

Lambda Adjustment for 6-DOF Simulation

The lambda's for 6-DOF simulation are computed from the so-called 'hybrid-slosh model'. The hybrid model was developed to improve the slosh model in the bottom half of the ellipsoidal section of the tank. Two methods were employed and combined to match better with flight data. The first is the equivalent cylinder method from the reference (NASA SP-106) to compute slosh frequency above 119 inches from the bottom of feedline for LO₂ and 78 inches from the bottom of tank for LH₂. These cut-off heights are equivalent to the 3g limiting point for LO₂ in flight. The second method employed is ramping the frequency below those cut-off surface heights to the frequency of the hemisphere model at MECO. The ramping frequency between the 3g limiting point and MECO was designed to match the simulation model with flight data at the 3g limiting point and MECO point. The lambda is extracted out of ramped slosh frequency using the AX and surface radius from the equation below:

$$\text{Slosh frequency} = \text{lambda} * \text{SQRT}(\text{AX} / \text{surface radius from tanking table})$$

The lambda was smoothed out using the 6th order polynomial fit below 78" of height from the tank bottom. In this section of the tank, the lambdas for both LO₂ and LH₂ are the same. The above equation should be used to compute the slosh frequency as well as for the simulation. The lambda from the hybrid model is provided in a separate column of Tables 3.3.1.2.1 and 3.3.1.2.2 for the GN&C 6-DOF simulation.

Reduction of Data Points

Because the original tanking tables have more data points than required, it was decided to reduce the number of points to use for practical purposes. An algorithm was developed to select the points that have the differences between the original data and the interpolated points below the defined tolerance level. The radius data at the baffle are not selected in the reduced set of data since the effect of the baffle is insignificant to slosh frequency. The tolerances used to select the data points are listed below:

Parameters	Tolerance for LO ₂	Tolerance for LH ₂
Surface Radius (in)	0.2	0.2
Surface Height (in)	0.1	0.1
Lambda	0.001	0.001
Slosh Mass (slug)	2.0	0.3
X CG of slosh mass (in)	0.1	0.1

Data Interpolation

Tables 3.3.1.2.1 and 3.3.1.2.2 show the reduced tank table with the slosh model parameters for LWT LO₂ and LH₂, respectively. The SLWT tanking tables are tabulated in Table 3.3.1.2.3 and 3.3.1.2.4. These slosh model parameters are to be read from the table with the liquid volume inside of the tank (exclude the volume in the feedline for LO₂ only) as an independent variable. The liquid volume is computed by dividing the liquid weight by the given density in the tanking table. Linear interpolation technique is recommended to compute the values between the data points from the table.

3.3.1.3 LO₂/LH₂ Damping Table

The four baffle LO₂ and LWT LH₂ damping tables with respect to surface height from the bottom of tank are shown in Tables 3.3.1.3.1 and 3.3.1.3.2, respectively. Tables 3.3.1.3.3 and 3.3.1.3.4 are three baffle LO₂ and SLWT LH₂ dampings. These damping tables are used with respect to surface height from the tanking table using linear interpolation between points. It is noted that both high and low ends of data were added to complete the damping at all heights. Figure 3.3.1.3-1 shows the LO₂ damping curves for 3 and 4 baffle configurations. The LH₂ damping curves for LWT and SLWT are shown in Figure 3.3.1.3-2.

3.3.1.4 Slosh Equations of Motion

Slosh equations of motion in terms of force and moment equations are provided in this section.

The slosh model was developed utilizing second order spring-mass-damper equations of motion. Only the fundamental mode of slosh motion is considered since the effective forces from the higher frequency modes are not significant. The slosh cant effect was implicitly embedded in the model formulation. The Y and Z components of acceleration create quasi-static offsets of the slosh mass from the ET centerline. This offset accounts for the cant angle of the ET propellant. The vehicle linear accelerations in the Y and Z axes about the ET centerline, as well as the pitch and yaw rotational dynamics, were used for slosh mass motion computations. However, the roll axis dynamics about the ET centerline was considered negligible with the assumption of zero friction against the tank wall.

This section is divided into four subsections: Assumptions and Constraints, Slosh Mass Dynamics Model, Mass property adjustment, and Slosh Force and Moment computations.

3.3.1.4.1 Assumptions and Constraints

- a. ET is rigid and no slosh and flex coupling exists for the slosh dynamics.
- b. Fluids are inviscid and incompressible.
- c. Fluid density is constant.
- d. Fluid flow is irrotational.
- e. No fluid separation or wave break.
- f. Only linear dynamics with the fundamental slosh mode are modeled.
- g. This model is only valid for positive vehicle AX.
- h. Only Y and Z axes dynamics are considered.

Given the slosh model parameters consisting of LOX and LH₂ slosh masses (M_{LOX} and M_{LH_2}), slosh mass CG location from surface (H_{LOX} and H_{LH_2}), slosh frequencies (ω_{LOX} and ω_{LH_2}), and slosh damping ratios (ζ_{LOX} and ζ_{LH_2}) from the previous sections, the slosh dynamics equations are derived in the following sections. All dimensions are in feet for distance, slugs for mass, fps² for acceleration, pounds for forces, ft/lbs for moments, and slug-ft² for moments of inertia, unless specified otherwise. The subscript 's' is used in the equations in place of the 'LOX' or 'LH₂' subscript where the same equation applies to both fluids.

3.3.1.4.2 Slosh Mass Dynamics Model

A second order spring-mass-damper model is used to model the slosh dynamics. Two linear degrees of freedom are modeled. Slosh motion in the Y and Z axes is assumed

to be constrained to a plane perpendicular to the vertical (X) axis of the tank as shown in Figure 3.3.1.4-1.

The slosh mass acceleration relative to inertial space may be expressed as that of a “moving point” in a moving body coordinate system as shown in Figure 3.3.1.4-2.

$$\ddot{\bar{\mathbf{R}}}_2 = \ddot{\bar{\mathbf{R}}}_1 + \ddot{\bar{\mathbf{P}}}_s + \dot{\bar{\boldsymbol{\omega}}} \times \bar{\mathbf{P}} + \bar{\boldsymbol{\omega}} \times (\bar{\boldsymbol{\omega}} \times \bar{\mathbf{P}}) + 2\bar{\boldsymbol{\omega}} \times \dot{\bar{\mathbf{P}}}_s$$

where,

$\ddot{\bar{\mathbf{R}}}_2$ = acceleration of the slosh mass relative to inertial space expressed in body axes ($= [A_{sx} \ A_{sy} \ A_{sz}]^T$)

$\ddot{\bar{\mathbf{R}}}_1$ = inertial acceleration of the origin of the body frame ($= [A_x \ A_y \ A_z]^T$)

$\ddot{\bar{\mathbf{P}}}_s$ = acceleration of the slosh mass relative to the origin of the body frame ($= [0 \ \ddot{Y}_s \ \ddot{Z}_s]^T$)

$\dot{\bar{\mathbf{P}}}_s$ = velocity of the slosh mass relative to the origin of the body frame ($= [0 \ \dot{Y}_s \ \dot{Z}_s]^T$)

$\bar{\mathbf{P}}_s$ = position of the slosh mass relative to the ET centerline ($= [0 \ Y_s \ Z_s]^T$)

$\bar{\mathbf{P}}$ = position of the slosh mass relative to the origin of the rigid body frame ($= [P_x \ P_y \ P_z]^T = [L_{xs} (L_{ys} + Y_s) (L_{zs} + Z_s)]^T$)

$\dot{\bar{\boldsymbol{\omega}}}$ = angular acceleration of the body in inertial space ($= [\dot{p} \ \dot{q} \ \dot{r}]^T$)

$\bar{\boldsymbol{\omega}}$ = angular velocity of the body in inertial space ($= [p \ q \ r]^T$)

After substitutions and manipulations, the above equation becomes:

$$A_{sx} = A_x + \left[- (q^2 + r^2)P_x + (pq - \dot{r})P_y + (pr + \dot{q})P_z \right] + 2(q\dot{Z}_s - r\dot{Y}_s)$$

$$A_{sy} = A_y + \ddot{Y}_s + \left[(pq + \dot{r})P_x - (p^2 + r^2)P_y + (qr - \dot{p})P_z \right] - 2p\dot{Z}_s \quad (\text{Eqn. 1})$$

$$A_{sz} = A_z + \ddot{Z}_s + \left[(pr - \dot{q})P_x + (qr + \dot{p})P_y - (p^2 + q^2)P_z \right] - 2p\dot{Y}_s$$

The above equation defines the acceleration of the slosh mass relative to inertial space. The vector \bar{P}_s defines the relative position of the slosh mass to the slosh null position. The slosh spring-mass-damper system is modeled by being attached to the null position as shown in Figure 3.3.1.4-1, and forced to follow the motion of the rigid vehicle.

The summation of the forces and the corresponding acceleration components are:

$$\begin{aligned} SF_{sy} &= M_s A_{sy} \\ SF_{sz} &= M_s A_{sz} \end{aligned} \quad (\text{Eqn. 2})$$

and in terms of spring constant (K) and damping (C),

$$\begin{aligned} SF_{sy} &= -C \dot{Y}_s - K Y_s \\ SF_{sz} &= -C \dot{Z}_s - K Z_s \\ \text{where, } K &= \omega_s^2 M_s, \text{ and } C = 2\zeta_s \omega_s M_s \end{aligned}$$

Using the second order model for the slosh mass dynamics, the slosh acceleration equations can be written for the Y and Z axes as:

$$\begin{aligned} A_{sy} &= \ddot{Y}_{SI} = -2\zeta_s \omega_s \dot{Y}_s - \omega_s^2 Y_s \\ A_{sz} &= \ddot{Z}_{SI} = -2\zeta_s \omega_s \dot{Z}_s - \omega_s^2 Z_s \end{aligned}$$

where, \ddot{Y}_{SI} and \ddot{Z}_{SI} represent the Y and Z axes accelerations (fps²) of the slosh mass relative to inertial space in body coordinates, using the second order dynamics of the spring-mass-damper. Y_s and Z_s represent the displacement of the slosh mass with respect to its null position (ET centerline) in body coordinates. Vehicle Y and Z body axis coordinates are defined as the opposite of the inertial axis coordinate system using the right-hand rule, with the Z body axis is down, and the Y body axis is toward the right. ζ_s and ω_s represent the damping and frequency of the slosh mass.

Substituting Equations 2 into Equations 1, and assuming the Coriolis terms to be negligible, the equations in terms of slosh mass displacements, velocity and acceleration with respect to the vehicle body axis become:

$$\ddot{Y}_s = -2\zeta_s\omega_s\dot{Y}_s - \omega_s^2Y_s - A_y - (pq + r)L_{xs} + (p^2 - r^2)(L_{ys} + Y_s) - (qr - \dot{p})(L_{zs} + Z_s)$$

$$\ddot{Z}_s = -2\zeta_s\omega_s\dot{Z}_s - \omega_s^2Z_s - A_z - (pr - \dot{q})L_{xs} + (p^2 + q^2)(L_{zs} - Z_s) - (qr + \dot{p})(L_{ys} + Y_s)$$

$$\dot{Y}_s = \int \ddot{Y}_s dt + \dot{Y}_{s0} \quad \dot{Z}_s = \int \ddot{Z}_s dt + \dot{Z}_{s0}$$

$$Y_s = \int \dot{Y}_s dt + Y_{s0} \quad Z_s = \int \dot{Z}_s dt + Z_{s0}$$

where, A_y and A_z are the vehicle body accelerations (fps²) and p , q , r are the body rates (rad/sec). L_{xs} , L_{ys} , and L_{zs} are the distances between the vehicle CG and ET centerline (ft). $L_{zs} + Z_s$ represents the total distance between the vehicle CG and the slosh mass position along the Z axis. \ddot{Y}_s and \ddot{Z}_s are in ft/sec².

3.3.1.4.3 Rigid Body Mass Properties

The CG and mass of the vehicle rigid body are computed based upon the linear relationship between the uncanted total vehicle mass/CG and the slosh mass/CG. Nominal values for the slosh mass from the tanking tables (Table 3.3.1.2.1 through Table 3.3.1.2.4) were used to compute the x-locations of liquid surface and slosh mass CGs in ET coordinates. The rigid body moments of inertia are also computed from the total moments of inertia.

The vehicle rigid body mass without slosh mass, M_v is;

$$M_v = M - M_{LOX} - M_{LH_2}$$

where, M is the total vehicle mass (slugs) including the liquid in the ET, and M_{LOX} and M_{LH_2} are the slosh masses of LO₂ and LH₂ in slugs.

From Figure 3.3.1.4-3, the parameters are defined as (all dimensions in the equations are in feet):

X_{EBLOX} = bottom of LOX tank location in ET coordinates (80.285 ft = 963.425 in)

X_{EBLH} = bottom of LH₂ tank location in ET coordinates (181.106 ft = 2173.275 in)

X_{LOXET} = LOX surface location in ET coordinates

X_{LHET} = LH₂ surface location in ET coordinates

X_{LOXB} = LOX surface height from the tank bottom (= $X_{EBLOX} - X_{LOXET}$)

X_{LHB} = LH₂ surface height from the tank bottom (= $X_{EBLH} - X_{LHET}$)

$h1_{LOX}$ = LOX slosh Xcg from surface (= H_{LOX})

$h1_{LH}$ = LH slosh Xcg from surface (= H_{LH_2})

X_{EBLOX} and X_{EBLH} are constant, and X_{LOXB} , X_{LHB} , $h1_{LOX}$, $h1_{LH}$ are provided in the slosh parameter tables (Table 3.3.1.2.1 through Table 3.3.1.2.4). The surface locations in ET coordinates are:

$$X_{LOXET} = X_{EBLOX} - X_{LOXB}$$

$$X_{LHET} = X_{EBLH} - X_{LHB}$$

The nominal slosh mass CG locations in ET coordinates are:

$$X_{CGLX} = X_{LOXET} + h1_{LOX}$$

$$X_{CGLH} = X_{LHET} + h1_{LH}$$

Y_{CGLX} = 0 feet (center of ET tank)

Y_{CGLH} = 0 feet (center of ET tank)

Z_{CGLX} = 33.33 ft (= 400 inches) (from center of ET tank)

Z_{CGLH} = 33.33 ft (= 400 inches) (from center of ET tank)

The rigid body CGs are computed as:

$$X_{CG} = (X_{CGN} M - X_{CGLX} M_{LOX} - X_{CGLH} M_{LH_2}) / M_V$$

$$Y_{CG} = (Y_{CGN} M - Y_{CGLX} M_{LOX} - Y_{CGLH} M_{LH_2}) / M_V$$

$$Z_{CG} = (Z_{CGN} M - Z_{CGLX} M_{LOX} - Z_{CGLH} M_{LH_2}) / M_V$$

where,

X_{CGN} , Y_{CGN} , and Z_{CGN} are the CGs of the vehicle in ET coordinates (feet).

The rigid body moments of inertia are computed as:

$$I_{XX} = I_{XXN} - (M_V (D_{YCG}^2 + D_{ZCG}^2) + M_{LOX} (L_{YLOXT}^2 + L_{ZLOXT}^2) + M_{LH} (L_{YLHT}^2 + L_{ZLHT}^2))$$

$$I_{YY} = I_{YYN} - (M_V (D_{XCG}^2 + D_{ZCG}^2) + M_{LOX} (L_{XLOXT}^2 + L_{ZLOXT}^2) + M_{LH} (L_{XLHT}^2 + L_{ZLHT}^2))$$

$$I_{ZZ} = I_{ZZN} - (M_V (D_{XCG}^2 + D_{YCG}^2) + M_{LOX} (L_{XLOXT}^2 + L_{YLOXT}^2) + M_{LH} (L_{XLHT}^2 + L_{YLHT}^2))$$

$$I_{XY} = I_{XYN} - (M_V D_{XCG} D_{YCG} + M_{LOX} L_{XLOXT} L_{YLOXT} + M_{LH} L_{XLHT} L_{YLHT})$$

$$I_{XZ} = I_{XZN} - (M_V D_{XCG} D_{ZCG} + M_{LOX} L_{XLOXT} L_{ZLOXT} + M_{LH} L_{XLHT} L_{ZLHT})$$

$$I_{YZ} = I_{YZN} - (M_V D_{YCG} D_{ZCG} + M_{LOX} L_{YLOXT} L_{ZLOXT} + M_{LH} L_{YLHT} L_{ZLHT}),$$

where,

I_{XXN} , I_{YYN} , I_{ZZN} are the moments of inertia for the total integrated vehicle (slug-ft²)

I_{XYN} , I_{XZN} , I_{YZN} are the products of inertia for the total integrated vehicle (slug-ft²)

D_{XCG} ($=X_{CGN} - X_{CG}$) is the distance between total vehicle CG and rigid body CG in X axis

D_{YCG} ($=Y_{CGN} - Y_{CG}$) is the distance between total vehicle CG and rigid body CG in Y axis

D_{ZCG} ($=Z_{CGN} - Z_{CG}$) is the distance between total vehicle CG and rigid body CG in Z axis

L_{XLOXT} ($=X_{CGN} - X_{CGLX}$) is the distance between total vehicle CG and nominal LOX slosh mass CG in X axis

L_{YLOXT} ($=Y_{CGN} - Y_{CGLX}$) is the distance between total vehicle CG and nominal LOX slosh mass CG in Y axis

L_{ZLOXT} ($=Z_{CGN} - Z_{CGLX}$) is the distance between total vehicle CG and nominal LOX slosh mass CG in Z axis

L_{XLHT} ($=X_{CGN} - X_{CGLH}$) is the distance between total vehicle CG and nominal LH₂ slosh mass CG in X axis

L_{YLHT} ($=Y_{CGN} - Y_{CGLH}$) is the distance between total vehicle CG and nominal LH₂ slosh mass CG in Y axis

L_{ZLHT} ($=Z_{CGN} - Z_{CGLH}$) is the distance between total vehicle CG and nominal LH₂ slosh mass CG in Z axis

3.3.1.4.4 Slosh Force and Moment Computations

The slosh forces act on the vehicle rigid body mass. The total vehicle forces are expressed in terms of rigid mass and slosh mass as follows:

$$M_V A_Y = F_{YR} + F_{YS} = F_{YR} - M_S \ddot{Y}_{SI}$$

$$M_V A_Z = F_{ZR} + F_{ZS} = F_{ZR} - M_S \ddot{Z}_{SI}$$

where,

M_V is the vehicle rigid mass

A_Y and A_Z are the vehicle body accelerations along the Y and Z axes

F_{YR} , F_{ZR} are all forces, excluding slosh, acting on the rigid vehicle body, in Y and Z

F_{YS} , F_{ZS} are the forces due to slosh dynamics along the Y and Z axes

The slosh accelerations (\ddot{Y}_{SI} and \ddot{Z}_{SI}) were defined previously using the second order dynamics model, and the slosh force equations are expressed in terms of LOX and LH₂ as:

$$F_{YSLX} = - M_{LOX} - \ddot{Y}_{SILX} \quad : \text{LOX slosh force along the Y axis}$$

$$F_{ZSLX} = - M_{LOX} - \ddot{Z}_{SILX} \quad : \text{LOX slosh force along the Z axis}$$

$$F_{YSLH} = - M_{LH_2} - \ddot{Y}_{SILHH} \quad : \text{LH}_2 \text{ slosh force along the Y axis}$$

$$F_{ZSLH} = - M_{LH_2} - \ddot{Z}_{SILHH} \quad : \text{LO}_2 \text{ slosh force along the Z axis}$$

$$F_{YS} = F_{YSLX} + F_{YSLH} \quad : \text{Total slosh force along the Y axis}$$

$$F_{ZS} = F_{ZSLX} + F_{ZSLH} \quad : \text{Total slosh force along the Z axis}$$

The slosh moments are based on the slosh forces acting about the vehicle rigid body CG. The moment is computed by multiplying slosh force times moment arm (slosh mass CG minus vehicle CG). Since the roll slosh moment about the ET centerline is considered negligible for inviscid and irrotational fluid, the slosh roll moments about the ET centerline are zero. Therefore, a separate set of moment arms are computed for the roll axis.

The distances between vehicle CG and nominal slosh CGs (ET centerline) are:

$$L_{XLOX} = X_{CG} - X_{CGLX}$$

$$L_{YLOX} = Y_{CG} - Y_{CGLX}$$

$$L_{ZLOX} = Z_{CG} - Z_{CGLX}$$

$$L_{XLH} = X_{CG} - X_{CGLH}$$

$$L_{YLH} = Y_{CG} - Y_{CGLH}$$

$$L_{ZLH} = Z_{CG} - Z_{CGLH}$$

The distances between vehicle CG and computed slosh mass CGs are:

$$R_{XLOX} = L_{XLOX}$$

$$R_{YLOX} = L_{YLOX} + Y_{SLX}$$

$$R_{ZLOX} = L_{ZLOX} + Z_{SLX}$$

$$R_{XLH} = L_{XLH}$$

$$R_{YLH} = L_{YLH} + Y_{SLH}$$

$$R_{ZLH} = L_{ZLH} + Z_{SLH}$$

The roll slosh moments about the vehicle roll axis are:

$$L_{SLOX} = M_{LOX} (\ddot{Y}_{SILX} * L_{ZLOX} - \ddot{Z}_{SILX} * L_{YLOX})$$

$$L_{SLH} = M_{LH} (\ddot{Y}_{SILH} * L_{ZLH} - \ddot{Z}_{SILH} * L_{YLH})$$

$$L_{STOT} = L_{SLOX} + L_{SLH} \quad \text{[Total roll slosh moment]}$$

The pitch slosh moments about the vehicle pitch axis are:

$$M_{SLOX} = M_{LOX} (\ddot{Z}_{SILX} * R_{XLOX} - AX * R_{ZLOX})$$

$$M_{SLH} = M_{LH} (\ddot{Z}_{SILH} * R_{XLH} - AX * R_{ZLH})$$

$$M_{STOT} = M_{SLOX} + M_{SLH} \quad \text{[Total pitch slosh moment]}$$

The yaw slosh moments about the vehicle yaw axis are:

$$N_{SLOX} = M_{LOX} (AX * R_{YLOX} - \ddot{Y}_{SILX} * R_{XLOX})$$

$$N_{SLH} = M_{LH} (AX * R_{YLH} - \ddot{Y}_{SILH} * R_{XLH})$$

$$N_{STOT} = N_{SLOX} + N_{SLH} \quad \text{[Total yaw slosh moment]}$$

3.3.1.4.5 Slosh Model Implementation Applicability

- a. SSME Tail-off - The slosh mass computation is a function of tank geometry and is computed for positive AX. During SSME tail-off, AX is positive but decreasing rapidly. Computation of slosh mass during this portion of the trajectory is continued as the acceleration decreases and goes to zero to avoid a step change in the rigid body CG if the slosh mass were set to zero.
- b. Mated Coast Flight - The slosh model does not model the dynamics during zero or negative AX. Other models such as the finite element model are available for modeling this flight phase.

3.3.1.5 LO₂/LH₂ Propellant Mass Properties

Tables 3.3.1.5.1 and 3.3.1.5.2 provide propellant mass properties of the LH₂ and LOX contained in the ET as a function of propellant weight. Data is provided for propellant weights ranging from maximum fill to complete propellant depletion. The following variables are contained in separate tables for LOX and LH₂: propellant CGs in ET coordinate frame, moments of inertia about the propellant CG, and products of inertia about the propellant CG. The tables are intended to provide these propellant mass properties using propellant weight as the independent variable. Linear interpolation is recommended to compute mass properties between the data points in the table.

It should be noted that the mass properties provided include all propellant in the ET up to the tank/Orbiter interface. This includes propellant contained in the LOX and LH₂ tanks and feedlines as well as ullage pressurant.

3.4 SOLID ROCKET BOOSTER (SRB)

Two SRBs, illustrated in Figure 3-4, burn in parallel with the Orbiter MPS to provide initial ascent thrust. Primary elements of the booster are the motor, including case, propellant, igniter, and nozzle; structural systems; separation, Operational Flight Instrumentation (OFI), and recovery avionics; separation motors and pyrotechnics; and deceleration system, range safety destruct system, and Thrust Vector Control (TVC) subsystems. Each SRB weighs approximately 1.3 million pounds and produces an average thrust of approximately 2.34 million pounds at sea level. The propellant grain is shaped to reduce thrust approximately one-third at 55 seconds after lift-off to prevent overstressing the vehicle during the period of maximum dynamic pressure. The grain is of conventional design, employing a star perforation in the forward motor closure and a double truncated cone perforation in each of the segments and aft closure. The contoured nozzle expansion ratio (area of exit to area of throat) is 7.72. The SRB TVC, which is a closed-loop hydraulic system with power provided by redundant Auxiliary Power Units (APUs) and hydraulic pumps, has an omni-axial gimbal capability which, in conjunction with the Orbiter Main Engines, provides the flight control during the Shuttle boost phase.

A segmented case design affords maximum flexibility in fabrication and ease of transportation and handling. A cone-shaped skirt at the aft end of each of the SRBs carries the aft loads between the SRB and the Mobile Launch Pad (MLP). Two lateral sway braces and a diagonal attachment at the aft frame provide the structural attachment between the SRB and ET. The SRB forward attachment to the ET is by a single thrust attachment at the forward end of the forward skirt. The same forward skirt is used for attaching the main parachute riser attachments.

The SRBs are released from the ET by pyrotechnic separation devices at the forward thrust attachment and the aft attachments. Eight separation motors on each SRB, four aft and four forward, separate the SRBs from the ET.

The SRB forward section provides installation volume for the SRB electronics, recovery gear, range safety destruct system, and forward separation rockets. It also houses the parachute deceleration subsystem which consists of a pilot parachute, a ribbon drogue parachute, and three ribbon main parachutes.

3.5 SHUTTLE COORDINATE SYSTEMS AND DIMENSIONS

The Shuttle System and Shuttle elements X, Y, Z coordinate systems are defined in TMX-58153, Coordinate Systems for the SSP, (Figure 3-5). The X, Y, Z coordinate systems for the Orbiter, ET, SRB, and Shuttle System are designated by the subscript letters O, T, B, and S. The unit of measurement is the inch. The Shuttle Vehicle dimensions are presented in the inset for reference.

In each coordinate system, the X-axis zero point is located forward of the nose tip; that is, the Orbiter nose tip location is 236 inches aft of the zero point (at X_O 236); the ET ascent air data system's most forward point is at X_T 327.2; and the SRB nose tip location is at X_B 200. In the Orbiter, the horizontal X_O , Y_O reference plane is located at Z_O 400, which is 336.5 inches above the ET horizontal X_T , Y_T reference plane located at Z_T 400. The SRB horizontal X_B , Y_B reference plane is located at Z_B 0 and coincident with the ET horizontal plane at Z_T 400. The SRB central vertical X_B , Z_B planes are located at $+Y_S$ 250.5 and $-Y_S$ 250.5. Also, note that the Orbiter, ET, and Shuttle System center X, Z planes coincide.

From the $X = 0$ point, aft is positive, and forward is negative for all coordinate systems. Looking forward, each Shuttle element Y coordinate right of the centerplane (starboard) is positive, and left of center (port) is negative. The Z-axis of each coordinate system is perpendicular to the respective X-Y reference plane with each Z-coordinate below the X-Y reference plane being negative and each point above that plane being positive.

The Shuttle System and Shuttle elements coordinate systems are related as shown in Table 3.1. The basic Space Shuttle Vehicle dimensions are provided in Figure 3-6.

The natural body-fixed reference frame for the determination of rigid body dynamics is the dynamic body reference frame illustrated in Figure 3-7. The body-axis system upon which the aerodynamics are based is the aerodynamic body-axis system shown in Figure 3-8.

TABLE 3.1
SHUTTLE COORDINATE SYSTEM TRANSFORMATIONS

From:	To:		
	Orbiter System	Shuttle System/ External Tank System	Dynamic Reference System
Orbiter System X_O, Y_O, Z_O		$X_O + 741.0 = X_{S/T}$ $Y_O = Y_{S/T}$ $Z_O + 336.5 = Z_{S/T}$	$236.0 - X_O = X_D$ $Y_O = Y_D$ $63.5 - Z_O = Z_D$
Shuttle System/External Tank System X_S, Y_S, Z_S X_T, Y_T, Z_T	$X_{S/T} - 741.0 = X_O$ $Y_{S/T} = Y_O$ $Z_{S/T} - 336.5 = Z_O$		$977.0 - X_{S/T} = X_D$ $Y_{S/T} = Y_D$ $400.0 - Z_{S/T} = Z_D$
SRB (right) X_B, Y_B, Z_B	$X_B - 198.0 = X_O$ $Y_B + 250.5 = Y_O$ $Z_B + 63.5 = Z_O$	$X_B + 543.0 = X_{S/T}$ $Y_B + 250.5 = Y_{S/T}$ $Z_B + 400.0 = Z_{S/T}$	$434.0 = X_B = X_D$ $250.5 + Y_B = Y_D$ $- Z_B = Z_D$
SRB (left) X_B, Y_B, Z_B	$X_B - 198.0 = X_O$ $Y_B + 250.5 = Y_O$ $Z_B + 63.5 = Z_O$	$X_B + 543.0 = X_{S/T}$ $Y_B - 250.5 = Y_{S/T}$ $Z_B + 400.0 = Z_{S/T}$	$434.0 = X_B = X_D$ $- 250.5 + Y_B = Y_D$ $- Z_B = Z_D$
Dynamic Reference System X_D, Y_D, Z_D	$236.0 - X_D = X_O$ $Y_D = Y_O$ $63.5 - Z_D = Z_O$	$977.0 - X_D = X_{S/T}$ $Y_D = Y_{S/T}$ $400.0 - Y_D = Z_{S/T}$	
The aerodynamic moments are positive about the dynamic axis but aerodynamic forces (normal and axial) are negative in the Z and X directions.			

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE 3.3.1.2.1

EXTERNAL LIGHTWEIGHT TANK LO₂ SLOSH PARAMETER TABLE

CRYO PRESSURIZED CASE FOR LWT 68 AND SUBSEQUENT

UPDATED FOR SLOSH PARAMETERS, DEC. 1996
GN&C SYSTEMS
AVIONICS SYSTEMS, SPACE SYSTEMS DIVISION
BOEING REUSABLE SPACE SYSTEMS

PRESSURE = 22.0 PSIG, DENSITY = 71.19 LBS/CU-FT
TEMP = -297 DEG F, SENSOR LOCATION = 458.48 IN

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
0.00	0.0	20.84	0.00	0.00	0.3540	0.3216
1.03	1.0	23.76	1.90	1.00	0.3946	0.3773
2.62	2.0	29.61	4.83	1.64	0.4312	0.4331
4.67	3.0	33.58	8.60	2.27	0.4642	0.4782
7.34	4.0	38.28	13.49	2.75	0.4939	0.4922
10.77	5.0	43.46	19.81	3.13	0.5206	0.4931
14.97	6.0	48.08	27.53	3.56	0.5446	0.4996
19.94	7.0	52.28	36.65	4.01	0.5663	0.5084
25.68	8.0	56.18	47.18	4.47	0.5858	0.5177
32.18	9.0	59.80	59.09	4.94	0.6034	0.5276
39.44	10.0	63.18	72.37	5.42	0.6193	0.5377
47.44	11.0	66.35	87.00	5.91	0.6338	0.5477
56.11	12.0	69.07	102.82	6.45	0.6469	0.5607
75.43	14.0	74.18	137.96	7.52	0.6699	0.5836
97.61	16.0	79.35	178.29	8.50	0.6895	0.5996
122.60	18.0	84.05	223.61	9.51	0.7065	0.6160
165.21	21.0	90.46	300.62	11.05	0.7288	0.6396
213.82	24.0	96.29	388.07	12.62	0.7486	0.6618
268.23	27.0	101.61	485.54	14.21	0.7670	0.6828
349.50	31.0	108.07	630.30	16.35	0.7903	0.7093
440.36	35.0	113.92	791.02	18.52	0.8125	0.7342

TABLE 3.3.1.2.1

EXTERNAL LIGHTWEIGHT TANK LO₂ SLOSH PARAMETER TABLE - Continued

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
566.79	40.0	120.49	1012.74	21.28	0.8382	0.7637
706.75	45.0	126.37	1255.63	24.08	0.8609	0.7917
891.45	51.0	132.66	1572.06	27.51	0.8835	0.8236
1128.25	58.0	139.06	1970.69	31.61	0.9042	0.8592
1385.92	65.0	144.58	2394.96	35.81	0.9223	0.8935
1662.24	72.0	149.32	2838.23	40.14	0.9414	0.9268
1955.01	79.0	153.34	3293.35	44.60	0.9593	0.9593
2217.38	85.0	156.27	3687.51	48.53	0.9866	0.9866
2443.05	90.0	158.37	4015.02	51.89	1.0090	1.0090
2674.24	95.0	160.17	4338.49	55.33	1.0313	1.0313
2910.17	100.0	161.69	4654.89	58.85	1.0533	1.0533
3101.81	104.0	162.70	4900.84	61.72	1.0707	1.0707
3246.96	107.0	163.34	5079.94	63.91	1.0836	1.0836
3392.86	110.0	163.70	5247.62	66.27	1.0977	1.0977
3831.55	119.0	164.82	5725.17	73.04	1.1349	1.1349
3930.36	121.0	164.84	5817.91	74.69	1.1439	1.1439
4177.50	126.0	164.95	6040.73	78.68	1.1643	1.1643
4375.47	130.0	165.01	6206.07	81.83	1.1795	1.1795
4573.52	134.0	165.04	6359.53	84.94	1.1937	1.1937
4821.13	139.0	165.05	6536.12	88.76	1.2101	1.2101
5068.76	144.0	165.05	6697.47	92.48	1.2249	1.2249
5167.81	146.0	165.05	6758.02	93.94	1.2304	1.2304
5464.45	152.0	165.05	6926.74	98.20	1.2456	1.2456
5712.09	157.0	165.05	7053.67	101.64	1.2569	1.2569
6009.27	163.0	165.06	7190.98	105.63	1.2691	1.2691
6306.46	169.0	165.06	7313.04	109.47	1.2798	1.2798
6603.66	175.0	165.06	7421.24	113.16	1.2892	1.2892
6851.31	180.0	165.06	7502.01	116.11	1.2962	1.2962
7247.05	188.0	165.06	7615.63	120.61	1.3059	1.3059
7593.79	195.0	165.06	7700.30	124.34	1.3131	1.3131
7940.50	202.0	165.05	7772.24	127.88	1.3194	1.3194
8039.53	204.0	165.01	7787.03	128.88	1.3211	1.3211
8089.05	205.0	165.04	7799.87	129.34	1.3218	1.3218
8287.06	209.0	164.99	7829.02	131.26	1.3249	1.3249

TABLE 3.3.1.2.1

EXTERNAL LIGHTWEIGHT TANK LO₂ SLOSH PARAMETER TABLE - Continued

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
8385.98	211.0	164.93	7838.34	132.21	1.3264	1.3264
9174.45	227.0	164.83	7932.55	139.05	1.3356	1.3356
9223.82	228.0	164.79	7933.17	139.47	1.3361	1.3361
9273.20	229.0	164.80	7940.22	139.85	1.3366	1.3366
9519.74	234.0	164.61	7940.49	141.84	1.3390	1.3390
9716.48	238.0	164.41	7932.84	143.37	1.3407	1.3407
10010.58	244.0	164.04	7908.60	145.58	1.3432	1.3432
10303.25	250.0	163.61	7872.06	147.64	1.3453	1.3453
10497.42	254.0	163.27	7838.01	148.94	1.3466	1.3466
10594.22	256.0	163.12	7823.40	149.56	1.3472	1.3472
10931.35	263.0	162.47	7752.00	151.61	1.3491	1.3491
11218.04	269.0	161.85	7679.31	153.20	1.3505	1.3505
11549.57	276.0	161.05	7581.13	154.84	1.3518	1.3518
11877.62	283.0	160.17	7469.47	156.26	1.3529	1.3529
12063.39	287.0	159.62	7398.98	156.96	1.3535	1.3535
12385.31	294.0	158.61	7267.63	158.00	1.3543	1.3543
12702.96	301.0	157.51	7125.32	158.79	1.3550	1.3550
13016.04	308.0	156.33	6971.64	159.33	1.3555	1.3555
13324.22	315.0	155.07	6807.32	159.60	1.3559	1.3559
13627.22	322.0	153.71	6633.65	159.62	1.3562	1.3562
13924.72	329.0	152.28	6451.39	159.38	1.3564	1.3564
14257.67	337.0	150.53	6233.08	158.80	1.3565	1.3565
14582.69	345.0	148.67	6006.09	157.88	1.3567	1.3567
14899.38	353.0	146.69	5769.70	156.65	1.3567	1.3567
15207.37	361.0	144.59	5526.86	155.12	1.3568	1.3568
15543.00	370.0	142.10	5246.10	153.05	1.3568	1.3568
15795.79	377.0	140.06	5023.32	151.21	1.3568	1.3568
16109.82	386.0	137.30	4732.12	148.56	1.3568	1.3568
16411.08	395.0	134.38	4436.77	145.63	1.3568	1.3568
16636.30	402.0	132.00	4205.34	143.17	1.3568	1.3568
16883.70	410.0	129.17	3940.53	140.18	1.3568	1.3568
17120.19	418.0	126.20	3674.98	137.01	1.3568	1.3568
17427.02	429.0	121.91	3312.50	132.38	1.3568	1.3568
17559.54	434.0	119.94	3154.89	130.25	1.3568	1.3568

TABLE 3.3.1.2.1

EXTERNAL LIGHTWEIGHT TANK LO₂ SLOSH PARAMETER TABLE - Concluded

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
17762.35	442.0	116.61	2898.79	126.63	1.3568	1.3568
17953.60	450.0	113.14	2647.74	122.87	1.3568	1.3568
18154.76	459.0	109.05	2371.12	118.43	1.3568	1.3568
18321.09	467.0	105.27	2132.69	114.32	1.3568	1.3568
18494.11	476.0	100.85	1875.25	109.52	1.3568	1.3568
18635.41	484.0	96.76	1656.42	105.08	1.3568	1.3568
18764.98	492.0	92.50	1447.13	100.46	1.3568	1.3568
18882.92	500.0	88.10	1250.22	95.68	1.3568	1.3568
18976.74	507.0	84.15	1089.60	91.39	1.3568	1.3568
19061.99	514.0	80.08	938.96	86.97	1.3568	1.3568
19138.83	521.0	75.87	798.47	82.39	1.3568	1.3568
19198.14	527.0	72.17	687.12	78.37	1.3568	1.3568
19251.55	533.0	68.37	584.23	74.25	1.3568	1.3568
19299.21	539.0	64.50	490.62	70.05	1.3568	1.3568
19341.35	545.0	60.47	404.19	65.67	1.3568	1.3568
19372.39	550.0	57.07	339.76	61.97	1.3568	1.3568
19399.87	555.0	53.58	281.31	58.19	1.3568	1.3568
19423.92	560.0	49.99	228.45	54.29	1.3568	1.3568
19436.78	563.0	47.86	200.39	51.97	1.3568	1.3568
19452.16	567.0	44.93	165.80	48.79	1.3568	1.3568
19465.61	571.0	41.87	134.16	45.47	1.3568	1.3568
19474.50	574.0	39.63	113.79	43.04	1.3568	1.3568
19484.83	578.0	36.53	89.12	39.67	1.3568	1.3568
19491.49	581.0	34.13	72.70	37.07	1.3568	1.3568
19499.03	585.0	31.03	54.65	33.70	1.3568	1.3568
19503.73	588.0	28.52	42.41	30.97	1.3568	1.3568
19505.13	589.0	27.77	39.15	30.16	1.3568	1.3568
19506.40	590.0	26.49	34.00	28.77	1.3568	1.3568
19507.30	591.1	19.57	13.70	21.25	1.3568	1.3568

TABLE 3.3.1.2.2

EXTERNAL LIGHTWEIGHT TANK LH₂ SLOSH PARAMETER TABLE

CRYO PRESSURIZED CASE FOR LWT 7 AND SUBSEQUENT

UPDATED FOR SLOSH PARAMETERS, DEC. 1996
GN&C SYSTEMS
AVIONICS SYSTEMS, SPACE SYSTEMS DIVISION
BOEING REUSABLE SPACE SYSTEMS

PRESSURE = 29.3 PSIG, DENSITY = 4.414 LBS/CU-FT
TEMP = -423 DEG F, SENSOR LOCATION = 1077.0 IN

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
0.28	1.0	12.48	0.03	1.00	0.3946	0.5193
1.34	2.0	24.09	0.15	1.27	0.4312	0.4218
3.18	3.0	31.82	0.36	1.72	0.4642	0.4281
5.80	4.0	37.97	0.66	2.21	0.4939	0.4437
9.19	5.0	43.21	1.05	2.71	0.5206	0.4600
13.35	6.0	47.84	1.52	3.20	0.5446	0.4757
18.27	7.0	51.99	2.08	3.71	0.5663	0.4909
23.93	8.0	55.82	2.73	4.22	0.5858	0.5048
30.33	9.0	59.33	3.46	4.73	0.6034	0.5184
37.47	10.0	62.65	4.27	5.24	0.6193	0.5308
45.35	11.0	65.83	5.16	5.74	0.6338	0.5420
53.96	12.0	68.81	6.13	6.25	0.6469	0.5530
114.37	15.0	73.73	12.77	11.49	0.6801	0.7195
125.27	16.0	77.45	14.03	11.41	0.6895	0.7004
137.09	17.0	80.61	15.37	11.53	0.6983	0.6904
162.95	19.0	85.51	18.27	12.18	0.7143	0.6892
206.97	22.0	91.89	23.19	13.40	0.7356	0.6968
256.96	25.0	97.57	28.73	14.74	0.7548	0.7089
312.69	28.0	102.79	34.89	16.16	0.7729	0.7226
395.66	32.0	109.12	44.01	18.13	0.7959	0.7418
488.13	36.0	114.86	54.10	20.16	0.8178	0.7616

TABLE 3.3.1.2.2

EXTERNAL LIGHTWEIGHT TANK LH₂ SLOSH PARAMETER TABLE - Continued

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
616.46	41.0	121.33	67.98	22.79	0.8430	0.7864
758.17	46.0	127.11	83.15	25.51	0.8651	0.8111
944.72	52.0	133.26	102.85	28.86	0.8868	0.8404
1183.23	59.0	139.47	127.57	32.92	0.9068	0.8741
1441.57	66.0	144.58	153.64	37.20	0.9249	0.9089
1717.24	73.0	149.07	180.73	41.54	0.9443	0.9415
1965.68	79.0	152.29	204.36	45.41	0.9695	0.9695
2447.82	90.0	157.62	248.54	52.43	1.0154	1.0154
2818.11	98.0	160.94	280.81	57.59	1.0461	1.0461
3104.48	104.0	162.68	304.03	61.78	1.0711	1.0711
3395.65	110.0	163.79	325.73	66.25	1.0974	1.0974
3444.44	111.0	163.82	328.96	67.09	1.1026	1.1026
4128.51	125.0	164.83	371.60	77.98	1.1611	1.1611
4474.47	132.0	164.92	389.29	83.48	1.1874	1.1874
4870.34	140.0	165.03	407.24	89.53	1.2132	1.2132
5217.12	147.0	165.10	421.05	94.62	1.2328	1.2328
5415.35	151.0	165.10	428.04	97.47	1.2430	1.2430
5861.35	160.0	165.10	441.96	103.63	1.2630	1.2630
6257.79	168.0	165.10	452.45	108.82	1.2780	1.2780
6802.43	179.0	165.00	463.82	115.58	1.2951	1.2951
7099.31	185.0	164.96	469.05	119.04	1.3028	1.3028
7692.70	197.0	164.89	477.62	125.49	1.3155	1.3155
8383.39	211.0	164.92	485.88	132.19	1.3264	1.3264
8878.04	221.0	164.97	490.69	136.54	1.3323	1.3323
9570.99	235.0	165.01	495.86	142.05	1.3388	1.3388
10313.52	250.0	165.01	499.62	147.26	1.3439	1.3439
11105.51	266.0	165.00	502.47	152.09	1.3478	1.3478
11649.88	277.0	164.95	503.45	155.02	1.3498	1.3498
12489.90	294.0	164.80	503.83	158.95	1.3521	1.3521
14361.73	332.0	165.05	508.13	165.66	1.3547	1.3547
16937.24	384.0	165.05	509.25	171.51	1.3562	1.3562
18522.19	416.0	165.06	509.51	173.80	1.3565	1.3565
20305.29	452.0	165.06	509.66	175.59	1.3567	1.3567
22682.77	500.0	165.06	509.73	177.10	1.3568	1.3568

NSTS 08209, Volume I
Revision B

3-24

CHANGE NO. 47

TABLE 3.3.1.2.2

EXTERNAL LIGHTWEIGHT TANK LH₂ SLOSH PARAMETER TABLE - Continued

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
26639.21	580.0	165.04	509.63	178.35	1.3568	1.3568
32284.78	694.0	165.04	509.64	178.99	1.3568	1.3568
39014.42	830.0	165.05	509.71	179.19	1.3568	1.3568
47929.35	1010.0	165.05	509.72	179.24	1.3568	1.3568
49165.52	1035.0	164.77	507.15	178.94	1.3568	1.3568
49654.99	1045.0	164.27	502.52	178.39	1.3568	1.3568
49899.05	1050.0	163.59	496.31	177.66	1.3568	1.3568
50092.54	1054.0	162.80	489.12	176.80	1.3568	1.3568
50283.86	1058.0	161.82	480.35	175.73	1.3568	1.3568
50472.61	1062.0	160.66	470.09	174.47	1.3568	1.3568
50658.39	1066.0	159.31	458.37	173.01	1.3568	1.3568
50840.77	1070.0	157.77	445.22	171.34	1.3568	1.3568
51019.36	1074.0	156.04	430.71	169.46	1.3568	1.3568
51193.73	1078.0	154.11	414.89	167.36	1.3568	1.3568
51363.49	1082.0	151.96	397.81	165.03	1.3568	1.3568
51528.21	1086.0	149.60	379.53	162.46	1.3568	1.3568
51687.50	1090.0	147.00	360.13	159.65	1.3568	1.3568
51840.93	1094.0	144.17	339.70	156.57	1.3568	1.3568
51988.11	1098.0	141.08	318.31	153.21	1.3568	1.3568
52128.61	1102.0	137.71	296.05	149.55	1.3568	1.3568
52262.04	1106.0	134.05	273.07	145.58	1.3568	1.3568
52387.97	1110.0	130.07	249.45	141.26	1.3568	1.3568
52506.00	1114.0	125.74	225.37	136.55	1.3568	1.3568
52589.09	1117.0	122.24	207.09	132.76	1.3568	1.3568
52667.34	1120.0	118.51	188.67	128.70	1.3568	1.3568
52740.57	1123.0	114.51	170.23	124.36	1.3568	1.3568
52808.59	1126.0	110.23	151.82	119.71	1.3568	1.3568
52871.26	1129.0	105.62	133.56	114.70	1.3568	1.3568
52909.97	1131.0	102.35	121.54	111.15	1.3568	1.3568
52946.16	1133.0	98.89	109.64	107.40	1.3568	1.3568
52979.79	1135.0	95.24	97.93	103.43	1.3568	1.3568
53010.81	1137.0	91.37	86.47	99.23	1.3568	1.3568
53039.16	1139.0	87.24	75.27	94.74	1.3568	1.3568
53052.31	1140.0	85.07	69.79	92.39	1.3568	1.3568

NSTS 08209, Volume I
Revision B

3-25

CHANGE NO. 47

TABLE 3.3.1.2.2

EXTERNAL LIGHTWEIGHT TANK LH₂ SLOSH PARAMETER TABLE - Concluded

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
53064.79	1141.0	82.82	64.41	89.95	1.3568	1.3568
53076.56	1142.0	80.49	59.12	87.41	1.3568	1.3568
53087.64	1143.0	78.07	53.94	84.78	1.3568	1.3568
53098.02	1144.0	75.54	48.87	82.04	1.3568	1.3568
53107.68	1145.0	72.91	43.93	79.18	1.3568	1.3568
53116.65	1146.0	70.23	39.27	76.27	1.3568	1.3568
53124.93	1147.0	67.51	34.87	73.31	1.3568	1.3568
53132.48	1148.0	64.41	30.29	69.95	1.3568	1.3568
53139.28	1149.0	61.18	25.96	66.44	1.3568	1.3568
53145.34	1150.0	57.73	21.81	62.70	1.3568	1.3568
53150.65	1151.0	54.04	17.89	58.69	1.3568	1.3568
53155.20	1152.0	50.05	14.21	54.35	1.3568	1.3568
53159.00	1153.0	45.66	10.79	49.59	1.3568	1.3568
53162.02	1154.0	40.77	7.68	44.28	1.3568	1.3568
53164.27	1155.0	35.16	4.93	38.18	1.3568	1.3568
53165.73	1156.0	28.39	2.60	30.84	1.3568	1.3568
53166.47	1157.5	8.17	0.06	8.87	1.3568	1.3568

TABLE 3.3.1.2.3

EXTERNAL SUPER LIGHTWEIGHT TANK LO₂ SLOSH PARAMETER TABLE

CRYO PRESSURIZED CASE FOR SLWT

UPDATED FOR SLOSH PARAMETERS, DEC. 1996
GN&C SYSTEMS
AVIONICS SYSTEMS, SPACE SYSTEMS DIVISION
BOEING REUSABLE SPACE SYSTEMS

PRESSURE = 22.0 PSIG, DENSITY = 71.11 LBS/CU-FT
TEMP = -297 DEG F, SENSOR LOCATION = 421.60 IN

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
0.00	0.0	15.66	0.00	0.00	0.3540	0.3216
0.98	1.0	23.26	1.82	1.00	0.3946	0.3812
2.77	2.0	31.37	5.12	1.55	0.4312	0.4086
5.07	3.0	35.55	9.34	2.20	0.4642	0.4576
8.02	4.0	40.30	14.77	2.71	0.4939	0.4768
11.60	5.0	44.36	21.34	3.24	0.5206	0.4962
15.79	6.0	48.01	29.02	3.76	0.5446	0.5140
20.59	7.0	51.39	37.81	4.28	0.5663	0.5298
26.01	8.0	54.57	47.70	4.79	0.5858	0.5439
32.07	9.0	57.74	58.78	5.28	0.6034	0.5547
38.80	10.0	60.86	71.08	5.74	0.6193	0.5636
46.30	11.0	64.22	84.79	6.16	0.6338	0.5679
54.66	12.0	67.83	100.10	6.52	0.6469	0.5685
73.18	14.0	72.53	133.74	7.62	0.6699	0.5942
94.45	16.0	77.75	172.40	8.56	0.6895	0.6079
118.53	18.0	82.55	216.06	9.53	0.7065	0.6220
159.81	21.0	89.12	290.67	11.02	0.7288	0.6432
207.11	24.0	95.04	375.80	12.55	0.7486	0.6641
260.24	27.0	100.47	471.01	14.10	0.7670	0.6841
339.85	31.0	107.01	612.84	16.21	0.7903	0.7098
429.09	35.0	112.94	770.77	18.36	0.8125	0.7342

TABLE 3.3.1.2.3

EXTERNAL SUPER LIGHTWEIGHT TANK LO₂ SLOSH PARAMETER TABLE - Continued

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
553.55	40.0	119.59	989.15	21.09	0.8382	0.7633
691.63	45.0	125.58	1229.02	23.87	0.8609	0.7907
874.21	51.0	131.96	1542.18	27.27	0.8835	0.8222
1108.66	58.0	138.41	1937.21	31.35	0.9042	0.8579
1363.98	65.0	143.93	2357.77	35.57	0.9223	0.8926
1678.61	73.0	149.38	2862.46	40.49	0.9443	0.9301
1928.76	79.0	152.84	3251.30	44.30	0.9611	0.9578
1971.53	80.0	153.36	3316.53	44.95	0.9624	0.9624
2233.94	86.0	156.26	3709.30	48.88	0.9896	0.9896
2459.58	91.0	158.36	4035.90	52.23	1.0118	1.0118
2690.68	96.0	160.13	4357.95	55.67	1.0340	1.0340
2926.44	101.0	161.62	4672.56	59.19	1.0559	1.0559
3166.05	106.0	162.82	4976.40	62.80	1.0776	1.0776
3311.35	109.0	163.38	5151.19	65.04	1.0908	1.0908
3650.23	116.0	164.29	5530.36	70.34	1.1208	1.1208
3797.78	119.0	164.56	5683.17	72.66	1.1334	1.1334
4093.38	125.0	164.69	5956.91	77.50	1.1590	1.1590
4290.85	129.0	164.84	6129.61	80.61	1.1741	1.1741
4538.15	134.0	165.01	6331.44	84.41	1.1914	1.1914
4736.33	138.0	165.12	6481.92	87.40	1.2042	1.2042
4885.07	141.0	165.14	6584.77	89.66	1.2135	1.2135
5132.89	146.0	165.11	6740.67	93.38	1.2282	1.2282
5380.61	151.0	165.07	6882.39	97.00	1.2414	1.2414
5677.80	157.0	165.06	7036.94	101.17	1.2554	1.2554
5875.95	161.0	165.07	7132.66	103.85	1.2637	1.2637
6123.68	166.0	165.09	7242.31	107.11	1.2732	1.2732
6420.96	172.0	165.09	7359.01	110.89	1.2834	1.2834
6817.30	180.0	165.07	7492.74	115.70	1.2952	1.2952
7213.63	188.0	165.09	7609.43	120.22	1.3051	1.3051
7461.41	193.0	165.11	7674.09	122.91	1.3104	1.3104
7709.24	198.0	165.12	7732.67	125.50	1.3152	1.3152
7907.47	202.0	165.09	7770.27	127.53	1.3188	1.3188
9043.18	225.0	164.86	7920.66	137.97	1.3343	1.3343
9141.98	227.0	164.84	7930.22	138.79	1.3353	1.3353

TABLE 3.3.1.2.3

EXTERNAL SUPER LIGHTWEIGHT TANK LO₂ SLOSH PARAMETER TABLE - Continued

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
9290.09	230.0	164.79	7940.40	139.99	1.3367	1.3367
9388.75	232.0	164.69	7938.05	140.81	1.3377	1.3377
9438.07	233.0	164.71	7945.16	141.18	1.3381	1.3381
9733.45	239.0	164.44	7938.23	143.48	1.3408	1.3408
9831.65	241.0	164.32	7931.26	144.23	1.3417	1.3417
10125.29	247.0	163.89	7896.25	146.40	1.3440	1.3440
10320.17	251.0	163.58	7868.99	147.76	1.3454	1.3454
10755.78	260.0	162.82	7791.33	150.57	1.3481	1.3481
11139.31	268.0	162.05	7702.44	152.78	1.3501	1.3501
11471.69	275.0	161.28	7609.78	154.48	1.3515	1.3515
11660.14	279.0	160.80	7550.14	155.35	1.3522	1.3522
11847.43	283.0	160.29	7484.98	156.14	1.3528	1.3528
12079.80	288.0	159.62	7398.98	157.03	1.3535	1.3535
12310.15	293.0	158.89	7305.02	157.79	1.3541	1.3541
12629.00	300.0	157.82	7164.79	158.64	1.3548	1.3548
12809.20	304.0	157.17	7080.55	159.01	1.3551	1.3551
13076.63	310.0	156.15	6948.02	159.42	1.3555	1.3555
13427.54	318.0	154.68	6757.99	159.67	1.3560	1.3560
13728.96	325.0	153.31	6581.97	159.61	1.3562	1.3562
14066.62	333.0	151.63	6370.35	159.23	1.3565	1.3565
14396.60	341.0	149.84	6149.00	158.51	1.3566	1.3566
14638.81	347.0	148.42	5976.52	157.76	1.3567	1.3567
14954.40	355.0	146.43	5739.20	156.48	1.3567	1.3567
15223.37	362.0	144.59	5526.62	155.12	1.3568	1.3568
15522.24	370.0	142.37	5275.76	153.29	1.3568	1.3568
15776.04	377.0	140.35	5054.10	151.48	1.3568	1.3568
16056.99	385.0	137.91	4796.00	149.17	1.3568	1.3568
16361.06	394.0	135.03	4501.63	146.30	1.3568	1.3568
16620.37	402.0	132.34	4237.45	143.52	1.3568	1.3568
16838.54	409.0	129.86	4004.09	140.91	1.3568	1.3568
17106.74	418.0	126.54	3704.32	137.37	1.3568	1.3568
17305.60	425.0	123.84	3472.04	134.46	1.3568	1.3568
17388.11	428.0	122.59	3367.96	133.11	1.3568	1.3568
17469.06	431.0	121.44	3274.09	131.87	1.3568	1.3568

TABLE 3.3.1.2.3

EXTERNAL SUPER LIGHTWEIGHT TANK LO₂ SLOSH PARAMETER TABLE - Concluded

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
17651.76	438.0	118.57	3047.80	128.76	1.3568	1.3568
17897.46	448.0	114.32	2731.59	124.15	1.3568	1.3568
18103.06	457.0	110.28	2452.04	119.76	1.3568	1.3568
18273.36	465.0	106.58	2213.22	115.74	1.3568	1.3568
18450.89	474.0	102.20	1951.79	110.99	1.3568	1.3568
18596.19	482.0	98.17	1729.60	106.61	1.3568	1.3568
18729.76	490.0	93.99	1517.97	102.07	1.3568	1.3568
18851.69	498.0	89.64	1317.11	97.35	1.3568	1.3568
18948.93	505.0	85.72	1151.74	93.10	1.3568	1.3568
19037.47	512.0	81.65	995.17	88.67	1.3568	1.3568
19117.48	519.0	77.47	849.93	84.13	1.3568	1.3568
19179.41	525.0	73.80	734.79	80.14	1.3568	1.3568
19235.34	531.0	70.02	627.60	76.04	1.3568	1.3568
19285.46	537.0	66.15	529.18	71.84	1.3568	1.3568
19329.93	543.0	62.18	439.62	67.53	1.3568	1.3568
19362.83	548.0	58.80	371.62	63.85	1.3568	1.3568
19392.09	553.0	55.33	309.71	60.09	1.3568	1.3568
19417.82	558.0	51.77	253.63	56.22	1.3568	1.3568
19440.20	563.0	48.15	204.10	52.29	1.3568	1.3568
19459.39	568.0	44.46	160.70	48.29	1.3568	1.3568
19472.59	572.0	41.46	130.29	45.02	1.3568	1.3568
19483.96	576.0	38.40	103.54	41.70	1.3568	1.3568
19493.64	580.0	35.30	80.40	38.33	1.3568	1.3568
19501.71	584.0	32.12	60.60	34.89	1.3568	1.3568
19506.80	587.0	29.71	47.96	32.27	1.3568	1.3568
19511.10	590.0	27.23	36.91	29.57	1.3568	1.3568
19512.94	591.6	18.32	11.24	19.89	1.3568	1.3568

TABLE 3.3.1.2.4

EXTERNAL SUPER LIGHTWEIGHT TANK LH₂ SLOSH PARAMETER TABLE

CRYO PRESSURIZED CASE FOR SLWT

UPDATED FOR SLOSH PARAMETERS, DEC. 1996
GN&C SYSTEMS
AVIONICS SYSTEMS, SPACE SYSTEMS DIVISION
BOEING REUSABLE SPACE SYSTEMS

PRESSURE = 29.3 PSIG, DENSITY = 4.4213 LBS/CU-FT
TEMP = -423 DEG F, SENSOR LOCATION = 1044.6 IN

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
0.62	1.0	18.50	0.07	1.00	0.3946	0.4274
1.96	2.0	27.16	0.22	1.46	0.4312	0.4267
3.99	3.0	33.40	0.46	1.97	0.4642	0.4460
6.77	4.0	39.09	0.77	2.43	0.4939	0.4586
10.34	5.0	44.29	1.18	2.89	0.5206	0.4697
14.71	6.0	49.03	1.68	3.36	0.5446	0.4810
19.82	7.0	53.02	2.26	3.87	0.5663	0.4964
25.67	8.0	56.72	2.92	4.38	0.5858	0.5103
32.25	9.0	60.19	3.67	4.89	0.6034	0.5231
39.58	10.0	63.49	4.50	5.39	0.6193	0.5348
47.64	11.0	66.58	5.42	5.90	0.6338	0.5461
56.42	12.0	69.50	6.41	6.41	0.6469	0.5571
65.89	13.0	72.15	7.48	6.94	0.6589	0.5689
108.64	14.0	74.65	12.18	10.66	0.6699	0.6899
130.06	16.0	79.67	14.59	11.20	0.6895	0.6848
153.74	18.0	84.30	17.25	11.83	0.7065	0.6840
180.37	20.0	88.63	20.23	12.55	0.7217	0.6872
226.17	23.0	94.60	25.33	13.81	0.7422	0.6973
278.68	26.0	100.11	31.16	15.19	0.7610	0.7103
357.28	30.0	106.70	39.82	17.13	0.7846	0.7298
445.53	34.0	112.65	49.49	19.15	0.8070	0.7500

TABLE 3.3.1.2.4

EXTERNAL SUPER LIGHTWEIGHT TANK LH₂ SLOSH PARAMETER TABLE - Continued

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
568.70	39.0	119.29	62.86	21.77	0.8333	0.7757
705.38	44.0	125.25	77.55	24.46	0.8567	0.8008
886.07	50.0	131.59	96.72	27.78	0.8801	0.8305
1118.10	57.0	138.07	120.92	31.76	0.9015	0.8639
1407.35	65.0	144.42	150.42	36.42	0.9223	0.9007
1719.47	73.0	149.92	181.42	41.16	0.9443	0.9353
1967.23	79.0	153.00	205.01	45.05	0.9611	0.9643
2009.54	80.0	153.52	209.00	45.68	0.9687	0.9687
2402.28	89.0	157.62	244.93	51.52	1.0080	1.0080
2537.50	92.0	158.77	256.81	53.52	1.0210	1.0210
2629.15	94.0	160.03	265.36	54.54	1.0257	1.0257
2910.08	100.0	162.01	289.07	58.63	1.0509	1.0509
3246.81	107.0	163.63	315.47	63.71	1.0815	1.0815
3344.45	109.0	164.00	322.73	65.20	1.0902	1.0902
4510.25	133.0	164.92	390.99	84.04	1.1899	1.1899
4906.12	141.0	165.02	408.70	90.07	1.2155	1.2155
5104.24	145.0	165.07	416.72	92.98	1.2268	1.2268
5302.41	149.0	165.12	424.22	95.83	1.2372	1.2372
5699.23	157.0	165.21	437.68	101.35	1.2557	1.2557
5897.71	161.0	165.21	443.53	104.03	1.2640	1.2640
5996.88	163.0	165.21	446.29	105.35	1.2680	1.2680
6443.48	172.0	165.21	457.45	111.07	1.2837	1.2837
6641.89	176.0	165.16	461.52	113.54	1.2900	1.2900
6741.00	178.0	165.16	463.56	114.73	1.2928	1.2928
7236.60	188.0	165.07	472.08	120.49	1.3056	1.3056
7385.18	191.0	165.04	474.22	122.14	1.3090	1.3090
7533.66	194.0	165.02	476.32	123.74	1.3121	1.3121
7682.16	197.0	164.99	478.18	125.31	1.3150	1.3150
8472.30	213.0	165.07	487.87	132.92	1.3272	1.3272
8918.33	222.0	165.11	492.06	136.80	1.3325	1.3325
9017.44	224.0	165.16	493.22	137.60	1.3335	1.3335
9612.73	236.0	165.19	497.53	142.28	1.3389	1.3389
9761.47	239.0	165.19	498.39	143.38	1.3400	1.3400
9860.68	241.0	165.17	498.80	144.10	1.3408	1.3408

NSTS 08209, Volume I
Revision B

3-32

CHANGE NO. 47

TABLE 3.3.1.2.4

EXTERNAL SUPER LIGHTWEIGHT TANK LH₂ SLOSH PARAMETER TABLE - Continued

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
11150.00	267.0	165.16	503.91	152.31	1.3478	1.3478
14557.33	336.0	165.17	509.36	166.26	1.3549	1.3549
16442.08	374.0	165.17	510.20	170.68	1.3560	1.3560
17929.88	404.0	165.17	510.51	173.11	1.3564	1.3564
19467.18	435.0	165.17	510.67	174.92	1.3566	1.3566
20409.32	454.0	165.17	510.73	175.76	1.3567	1.3567
21847.38	483.0	165.17	510.78	176.75	1.3568	1.3568
22640.81	499.0	165.17	510.80	177.18	1.3568	1.3568
27047.45	588.0	165.16	510.68	178.54	1.3568	1.3568
35427.77	757.0	165.16	510.68	179.23	1.3568	1.3568
39239.94	834.0	165.19	510.99	179.34	1.3568	1.3568
40777.75	865.0	165.21	511.14	179.38	1.3568	1.3568
43804.34	926.0	165.22	511.30	179.41	1.3568	1.3568
44002.94	930.0	165.34	512.38	179.54	1.3568	1.3568
47731.19	1005.0	165.36	512.54	179.57	1.3568	1.3568
49218.93	1035.0	164.96	508.83	179.14	1.3568	1.3568
49416.46	1039.0	164.71	506.52	178.87	1.3568	1.3568
49662.23	1044.0	164.22	502.06	178.34	1.3568	1.3568
49857.58	1048.0	163.68	497.15	177.76	1.3568	1.3568
50099.56	1053.0	162.77	488.90	176.77	1.3568	1.3568
50290.91	1057.0	161.84	480.55	175.76	1.3568	1.3568
50479.82	1061.0	160.75	470.90	174.57	1.3568	1.3568
50711.91	1066.0	159.10	456.54	172.78	1.3568	1.3568
50893.84	1070.0	157.59	443.65	171.14	1.3568	1.3568
51115.91	1075.0	155.41	425.50	168.77	1.3568	1.3568
51288.80	1079.0	153.43	409.47	166.63	1.3568	1.3568
51457.00	1083.0	151.25	392.23	164.26	1.3568	1.3568
51620.11	1087.0	148.85	373.85	161.65	1.3568	1.3568
51777.72	1091.0	146.20	354.25	158.77	1.3568	1.3568
51929.43	1095.0	143.33	333.81	155.66	1.3568	1.3568
52039.09	1098.0	141.01	317.85	153.14	1.3568	1.3568
52179.48	1102.0	137.65	295.69	149.49	1.3568	1.3568
52312.84	1106.0	134.03	272.95	145.56	1.3568	1.3568
52438.75	1110.0	130.07	249.48	141.26	1.3568	1.3568

NSTS 08209, Volume I
Revision B

3-33

CHANGE NO. 47

TABLE 3.3.1.2.4

EXTERNAL SUPER LIGHTWEIGHT TANK LH₂ SLOSH PARAMETER TABLE - Concluded

FLUID VOLUME (CU-FT)	SURFACE HEIGHT FROM TANK BOTTOM (IN)	RADIUS OF SURFACE (IN)	SLOSH MASS (SLUG)	SLOSH XCG FROM SURFACE (IN)	SLOSH FREQ FACTOR (LAMBDA) FOR GN&C	SLOSH FREQ FACTOR (LAMBDA) FOR FCS
52556.82	1114.0	125.77	225.55	136.59	1.3568	1.3568
52666.65	1118.0	121.10	201.30	131.51	1.3568	1.3568
52743.37	1121.0	117.31	183.02	127.40	1.3568	1.3568
52815.07	1124.0	113.28	164.79	123.02	1.3568	1.3568
52881.55	1127.0	108.92	146.50	118.29	1.3568	1.3568
52942.63	1130.0	104.23	128.35	113.19	1.3568	1.3568
52980.27	1132.0	100.90	116.46	109.58	1.3568	1.3568
53015.40	1134.0	97.41	104.77	105.78	1.3568	1.3568
53047.99	1136.0	93.72	93.33	101.78	1.3568	1.3568
53063.31	1137.0	91.80	87.69	99.69	1.3568	1.3568
53091.91	1139.0	87.60	76.19	95.13	1.3568	1.3568
53117.71	1141.0	83.08	65.02	90.23	1.3568	1.3568
53129.55	1142.0	80.70	59.58	87.64	1.3568	1.3568
53140.68	1143.0	78.24	54.30	84.97	1.3568	1.3568
53160.86	1145.0	73.25	44.56	79.55	1.3568	1.3568
53169.93	1146.0	70.63	39.94	76.70	1.3568	1.3568
53178.30	1147.0	67.84	35.39	73.67	1.3568	1.3568
53185.99	1148.0	65.04	31.19	70.63	1.3568	1.3568
53192.95	1149.0	61.88	26.86	67.20	1.3568	1.3568
53199.18	1150.0	58.52	22.72	63.56	1.3568	1.3568
53204.67	1151.0	54.95	18.81	59.68	1.3568	1.3568
53209.42	1152.0	51.11	15.13	55.50	1.3568	1.3568
53213.42	1153.0	46.94	11.73	50.98	1.3568	1.3568
53216.68	1154.0	42.35	8.61	45.99	1.3568	1.3568
53219.20	1155.0	37.19	5.83	40.38	1.3568	1.3568
53220.96	1156.0	31.15	3.43	33.83	1.3568	1.3568
53222.14	1157.6	9.44	0.10	10.25	1.3568	1.3568

TABLE 3.3.1.3.1
FOUR BAFFLE LO₂ DAMPING TABLE

TANK HEIGHT (IN)	LWT LOX DAMPING (%)
0.00	1.00
76.00	1.00
77.00	4.20
90.00	2.60
102.00	1.75
104.00	2.25
109.00	1.68
114.00	4.80
120.00	3.35
133.00	2.50
141.00	6.75
145.00	6.30
152.00	8.95
161.00	6.75
173.00	4.55
177.00	8.40
180.00	7.90
186.00	10.75
201.00	7.00
208.00	5.90
215.00	8.50
240.00	4.35
242.00	4.75
248.00	4.10
252.00	6.85
280.00	3.00
300.00	1.75
320.00	1.00
340.00	0.54
350.00	0.49
367.00	0.42
376.00	0.33
387.12	0.20
389.00	0.17
425.00	0.16
450.00	0.15
479.10	0.15
488.00	0.16
500.00	0.18
511.25	0.20
650.00	0.20

TABLE 3.3.1.3.2**LWT LH₂ DAMPING TABLE**

TANK HEIGHT (IN)	LWT LH ₂ DAMPING (%)
0.00	0.80
57.00	0.80
105.00	0.80
106.00	4.10
149.00	1.12
151.00	6.22
251.00	0.49
253.00	0.71
269.00	0.46
270.00	2.49
322.00	0.63
324.00	0.85
340.00	0.55
342.00	2.57
422.00	0.33
430.00	0.54
499.00	0.09
515.00	0.52
587.00	0.07
589.00	0.44
637.00	0.15
710.00	0.03
760.00	0.04
761.00	0.41
833.00	0.06
835.00	0.42
912.00	0.04
914.00	0.11
930.00	0.20
1038.00	0.02
1040.00	1.40
1050.00	1.21
1052.00	2.89
1096.00	0.01
1158.00	0.01

TABLE 3.3.1.3.3
THREE BAFFLE LO₂ DAMPING TABLE

TANK HEIGHT (IN)	SLWT LOX DAMPING (%)
0.00	1.00
77.00	1.00
78.00	4.16
90.00	2.66
102.00	1.79
103.00	2.19
108.00	1.74
114.00	4.82
120.00	3.41
136.00	2.49
151.00	5.41
165.00	3.26
180.00	2.38
181.00	6.37
185.00	5.73
187.00	10.17
212.00	5.00
225.00	3.62
227.00	3.52
240.00	2.23
252.00	1.53
253.00	1.99
257.00	1.79
258.00	5.48
285.00	2.44
299.00	1.60
300.00	1.54
325.00	0.62
340.00	0.54
350.00	0.49
367.00	0.42
376.00	0.33
387.12	0.20
389.00	0.17
425.00	0.16
450.00	0.15
479.10	0.15
488.00	0.16
500.00	0.18
511.25	0.20
650.00	0.20

TABLE 3.3.1.3.4
SLWT LH₂ DAMPING TABLE

TANK HEIGHT (IN)	SLWT LH ₂ DAMPING (%)
0.00	0.80
57.00	0.80
104.00	0.80
106.00	3.97
149.00	1.15
152.00	6.16
269.00	0.47
270.00	2.53
340.00	0.52
342.00	2.57
400.00	0.67
513.00	0.21
515.00	0.56
587.00	0.23
589.00	0.58
636.00	0.28
701.00	0.20
756.00	0.20
761.00	0.57
833.00	0.22
835.00	0.58
904.00	0.20
930.00	0.36
989.00	0.20
1030.00	0.17
1039.00	0.65
1040.00	1.48
1050.00	1.21
1052.00	2.89
1096.00	0.01
1158.00	0.01

TABLE 3.3.1.5.1
ET LH₂ DEPLETION SEQUENCE
(INCLUDES PRESSURANT)

WT (LB)	CENTER-OF-GRAVITY(IN)			MOMENTS OF INERTIA (SLUG-FT ²)			PRODUCTS OF INERTIA (SLUG-FT ²)		
	X	Y	Z	I _{XX}	I _{YY}	I _{ZZ}	P _{XY}	P _{XZ}	P _{YZ}
232368	1601.3	0.0	400.1	441.0	3930938	3930938	-492.7	1546.8	-88.2
227742	1611.8	0.0	400.1	441.0	3675824	3675828	-482.4	1514.3	-88.2
223117	1622.3	0.0	400.1	441.0	3432062	3432063	-472.1	1481.8	-88.2
218492	1632.8	0.0	400.1	441.0	3199114	3199112	-461.8	1449.5	-88.2
213867	1643.4	0.0	400.1	441.0	2976750	2976749	-451.5	1417.1	-88.2
209241	1654.0	0.0	400.1	441.0	2764795	2764793	-441.1	1384.7	-88.2
204616	1664.5	0.0	400.1	441.0	2563042	2563042	-430.8	1352.4	-88.2
199991	1675.1	0.0	400.1	441.0	2371257	2371256	-420.5	1320.1	-88.2
195366	1685.6	0.0	400.1	441.0	2189173	2189173	-410.2	1287.7	-88.2
190741	1696.2	0.0	400.1	441.0	2016550	2016548	-399.9	1255.4	-88.2
186116	1706.7	0.0	400.1	440.9	1853141	1853139	-389.6	1223.1	-88.2
181490	1717.3	0.0	400.1	440.9	1698733	1698731	-379.4	1190.8	-88.1
176865	1727.8	0.0	400.1	440.9	1553116	1553113	-369.1	1158.5	-88.1
172240	1738.4	0.0	400.1	440.9	1416077	1416076	-358.8	1126.2	-88.1
167615	1748.9	0.0	400.1	440.9	1287401	1287401	-348.5	1093.9	-88.1
162990	1759.4	0.0	400.1	440.9	1166865	1166863	-338.2	1061.6	-88.1
158365	1770.0	0.0	400.1	440.9	1054231	1054231	-327.9	1029.4	-88.1
153739	1780.5	0.0	400.1	440.9	949262	949261	-317.7	997.2	-88.1
149114	1791.0	0.0	400.1	440.9	851708	851706	-307.4	965.0	-88.1
144489	1801.5	0.0	400.1	440.9	761343	761342	-297.2	932.8	-88.1
139864	1812.0	0.0	400.1	440.9	677935	677933	-286.9	900.6	-88.1
135239	1822.5	0.0	400.1	440.8	601256	601255	-276.7	868.5	-88.1
130614	1833.0	0.0	400.1	440.8	531095	531093	-266.4	836.3	-88.1
125988	1843.5	0.0	400.1	440.8	467223	467223	-256.2	804.2	-88.1
121363	1853.9	0.0	400.1	440.8	409416	409415	-246.0	772.2	-88.1

TABLE 3.3.1.5.1
ET LH₂ DEPLETION SEQUENCE
(INCLUDES PRESSURANT) - Continued

WT (LB)	CENTER-OF-GRAVITY(IN)			MOMENTS OF INERTIA (SLUG-FT ²)			PRODUCTS OF INERTIA (SLUG-FT ²)		
	X	Y	Z	IXX	IYY	IZZ	PXY	PXZ	PYZ
116738	1864.4	0.0	400.1	440.8	357439	357439	-235.8	740.1	-88.1
112113	1874.8	0.0	400.1	440.8	311038	311038	-225.6	708.1	-88.1
107488	1885.3	0.0	400.1	440.8	269965	269965	-215.4	676.2	-88.1
102863	1895.7	0.0	400.1	440.7	233953	233952	-205.3	644.3	-88.1
98237	1906.1	-0.1	400.2	440.7	202740	202738	-195.1	612.5	-88.1
93612	1916.4	-0.1	400.2	440.7	176060	176060	-185.0	580.7	-88.1
88987	1926.8	-0.1	400.2	440.7	153651	153650	-174.9	549.0	-88.1
84362	1937.1	-0.1	400.2	440.6	135240	135240	-164.8	517.4	-88.1
79737	1947.4	-0.1	400.2	440.6	120549	120550	-154.8	485.9	-88.1
75111	1957.6	-0.1	400.2	440.6	109274	109274	-144.8	454.6	-88.0
70486	1967.8	-0.1	400.2	440.5	101090	101090	-134.9	423.3	-88.0
65861	1978.0	-0.1	400.2	440.5	95631	95631	-125.0	392.3	-88.0
61236	1988.0	-0.1	400.2	440.4	92508	92507	-115.1	361.4	-88.0
56611	1998.0	-0.1	400.3	440.4	91289	91288	-105.4	330.9	-88.0
51986	2007.8	-0.1	400.3	440.3	91534	91534	-95.8	300.7	-88.0
47360	2017.5	-0.1	400.3	440.2	92783	92783	-86.3	271.0	-87.9
42735	2027.0	-0.1	400.3	440.1	94060	94060	-77.1	241.9	-87.9
38110	2036.3	-0.1	400.4	439.9	94643	94642	-68.1	213.7	-87.9
33485	2045.1	-0.1	400.4	439.8	94872	94872	-59.4	186.6	-87.8
28860	2053.4	-0.2	400.5	439.5	94307	94307	-51.4	161.3	-87.7
24235	2060.7	-0.2	400.6	439.2	92539	92538	-44.2	138.8	-87.7
19609	2066.6	-0.2	400.7	438.8	89225	89225	-38.5	120.8	-87.5
19232	2067.0	-0.2	400.7	438.7	88879	88879	-38.1	119.6	-87.5
18854	2067.3	-0.2	400.8	438.7	88521	88521	-37.8	118.5	-87.5
18477	2067.7	-0.3	400.8	438.6	88151	88151	-37.4	117.5	-87.5

TABLE 3.3.1.5.1
ET LH₂ DEPLETION SEQUENCE
(INCLUDES PRESSURANT) - Continued

WT (LB)	CENTER-OF-GRAVITY(IN)			MOMENTS OF INERTIA (SLUG-FT ²)			PRODUCTS OF INERTIA (SLUG-FT ²)		
	X	Y	Z	I _{XX}	I _{YY}	I _{ZZ}	P _{XY}	P _{XZ}	P _{YZ}
18099	2068.0	-0.3	400.8	438.6	87828	87828	-37.1	116.5	-87.5
17722	2068.2	-0.3	400.8	438.5	87459	87459	-36.9	115.7	-87.4
17344	2068.5	-0.3	400.8	438.4	87073	87073	-36.6	114.9	-87.4
16966	2068.7	-0.3	400.8	438.4	86660	86660	-36.4	114.2	-87.4
16589	2068.9	-0.3	400.9	438.3	86226	86226	-36.2	113.5	-87.4
16211	2069.1	-0.3	400.9	438.2	85784	85784	-36.0	113.0	-87.4
15834	2069.3	-0.3	400.9	438.2	85340	85340	-35.9	112.6	-87.3
15456	2069.4	-0.3	400.9	438.1	84891	84891	-35.8	112.3	-87.3
15074	2069.4	-0.3	400.9	438.0	84429	84429	-35.7	112.1	-87.3
14701	2069.4	-0.3	401.0	437.9	83949	83949	-35.7	112.0	-87.3
14324	2069.4	-0.3	401.0	437.9	83448	83448	-35.7	112.1	-87.3
13946	2069.3	-0.3	401.0	437.8	82927	82927	-35.8	112.3	-87.2
13568	2069.2	-0.3	401.1	437.7	82392	82392	-35.9	112.7	-87.2
13191	2069.0	-0.3	401.1	437.6	81846	81846	-36.1	113.3	-87.2
12813	2068.8	-0.4	401.1	437.5	81292	81292	-36.3	114.1	-87.1
12436	2068.5	-0.4	401.1	437.3	80728	80728	-36.7	115.0	-87.1
12058	2068.0	-0.4	401.2	437.2	80152	80152	-37.1	116.3	-87.1
11681	2067.6	-0.4	401.2	437.1	79557	79557	-37.5	117.8	-87.0
11303	2067.0	-0.4	401.3	437.0	78940	78940	-38.1	119.6	-87.0
10925	2066.3	-0.4	401.3	436.8	78299	78299	-38.8	121.7	-87.0
10548	2065.5	-0.4	401.4	436.7	77632	77632	-39.6	124.2	-86.9
10170	2064.5	-0.4	401.4	436.5	76941	76941	-40.5	127.1	-86.9
9793	2063.4	-0.5	401.5	436.3	76229	76229	-41.6	130.5	-86.8
9415	2062.2	-0.5	401.5	436.1	75497	75497	-42.8	134.3	-86.8
9038	2060.7	-0.5	401.6	435.9	74742	74742	-44.2	138.8	-86.7

TABLE 3.3.1.5.1
ET LH₂ DEPLETION SEQUENCE
(INCLUDES PRESSURANT) - Concluded

WT (LB)	CENTER-OF-GRAVITY(IN)			MOMENTS OF INERTIA (SLUG-FT2)			PRODUCTS OF INERTIA (SLUG-FT2)		
	X	Y	Z	IXX	IYY	IZZ	PXY	PXZ	PYZ
8660	2059.0	-0.5	401.6	435.7	73960	73960	-45.9	143.9	-86.6
8282	2057.1	-0.6	401.7	435.4	73144	73144	-47.7	149.8	-86.6
7905	2054.9	-0.6	401.8	435.1	72284	72284	-49.9	156.6	-86.5
7527	2052.3	-0.6	401.9	434.8	71372	71372	-52.4	164.4	-86.4
7150	2049.4	-0.6	402.0	434.5	70399	70399	-55.2	173.4	-86.3
6772	2046.0	-0.7	402.1	434.1	69362	69362	-58.6	183.8	-86.2
6395	2042.1	-0.7	402.2	433.7	68253	68253	-62.4	195.8	-86.1
6017	2037.5	-0.8	402.4	433.2	67065	67065	-66.8	209.8	-85.9
5640	2032.2	-0.8	402.5	432.7	65782	65782	-72.0	226.1	-85.8
5262	2025.9	-0.9	402.7	432.1	64378	64378	-78.2	245.5	-85.6
4884	2018.4	-0.9	402.9	431.4	62818	62818	-85.5	268.4	-85.4
4507	2009.4	-1.0	403.2	430.6	61051	61051	-94.2	295.8	-85.1
4129	1998.6	-1.1	403.4	429.6	59017	59017	-104.9	329.1	-84.9
3752	1985.2	-1.2	403.8	428.4	56640	56640	-117.9	370.1	-84.5
3374	1968.6	-1.3	404.2	427.0	53817	53817	-134.1	421.0	-84.1
2997	1947.5	-1.5	404.8	425.2	50385	50385	-154.7	485.6	-83.6
2619	1919.7	-1.7	405.4	422.9	46063	46063	-181.8	570.6	-82.9
2241	1881.8	-2.0	406.4	419.8	40354	40354	-218.8	686.9	-82.0
1864	1827.1	-2.4	407.7	415.3	32365	32365	-272.2	854.3	-80.8
1545	1762.3	-2.9	409.2	410.2	22231	22231	-335.4	1052.9	-79.3
1070	1594.5	0.0	400.0	0.0	0	0	0.0	0.0	0.0

TABLE 3.3.1.5.2

**ET LO₂ DEPLETION SEQUENCE
(INCLUDES PRESSURANT)**

WT (LB)	CENTER-OF-GRAVITY(IN)			MOMENTS OF INERTIA (SLUG-FT ²)			PRODUCTS OF INERTIA (SLUG-FT ²)		
	X	Y	Z	IXX	IYY	IZZ	PXY	PXZ	PYZ
1388248	725.3	0.5	401.3	74497	5379110	5328499	136938	317293	26984
1360542	731.0	0.6	401.4	74490	4727794	4677188	135968	315069	26980
1332836	736.3	0.6	401.4	74474	4284076	4233480	135038	312929	26975
1305130	741.5	0.6	401.4	74461	3904224	3853636	134144	310871	26970
1277424	746.5	0.6	401.4	74445	3596378	3545802	133279	308883	26964
1249718	751.3	0.6	401.5	74429	3355768	3305208	132441	306953	26959
1222012	756.1	0.7	401.5	74414	3158566	3108010	131624	305073	26953
1194306	760.7	0.7	401.5	74398	2983728	2933186	130825	303237	26947
1166600	765.2	0.7	401.6	74379	2823332	2772802	130041	301434	26941
1138894	769.6	0.7	401.6	74363	2679644	2629122	129269	299660	26934
1111188	774.0	0.7	401.7	74342	2557190	2506684	128507	297904	26927
1083482	778.4	0.7	401.7	74323	2456900	2406406	127753	296170	26920
1055776	782.7	0.8	401.7	74301	2374772	2324294	127004	294446	26912
1028070	787.0	0.8	401.8	74279	2304264	2253802	126259	292734	26904
1000364	791.3	0.8	401.8	74255	2239686	2189238	125517	291026	26895
972658	795.6	0.8	401.9	74231	2178574	2128146	124777	289325	26886
944952	799.9	0.8	402.0	74204	2121894	2071482	124037	287623	26876
917246	804.1	0.9	402.0	74176	2072468	2022077	123298	285923	26866
889539	808.4	0.9	402.1	74146	2032628	1982257	122558	284222	26855
861833	812.7	0.9	402.1	74115	2002538	1952189	121817	282517	26844
834127	817.0	1.0	402.2	74081	1979818	1929493	121074	280808	26831
806421	821.3	1.0	402.3	74045	1960672	1910369	120329	279095	26818
778715	825.6	1.0	402.4	74007	1941760	1891485	119582	277377	26804
751009	829.9	1.1	402.5	73965	1921854	1871604	118832	275652	26789

TABLE 3.3.1.5.2

**ET LO₂ DEPLETION SEQUENCE
(INCLUDES PRESSURANT) - Continued**

WT (LB)	CENTER-OF-GRAVITY(IN)			MOMENTS OF INERTIA (SLUG-FT ²)			PRODUCTS OF INERTIA (SLUG-FT ²)		
	X	Y	Z	IXX	IYY	IZZ	PXY	PXZ	PYZ
723303	834.2	1.1	402.6	73920	1902306	1852088	118079	273919	26773
695597	838.6	1.2	402.7	73872	1886108	1835923	117322	272179	26755
667891	843.0	1.2	402.8	73819	1875831	1825683	116561	270428	26736
640185	847.4	1.3	402.9	73762	1871698	1821588	115795	268664	26715
612479	851.9	1.3	403.0	73700	1870862	1820794	115022	266887	26693
584773	856.4	1.4	403.2	73633	1868695	1818672	114242	265092	26668
557067	861.0	1.4	403.3	73558	1861753	1811783	113453	263276	26641
529361	865.6	1.5	403.5	73476	1850678	1800764	112652	261434	26611
501655	870.3	1.6	403.7	73385	1840736	1790884	111838	259560	26577
473949	875.1	1.7	403.9	73283	1838343	1788560	111006	257649	26540
446243	880.0	1.8	404.1	73168	1844513	1794807	110155	255690	26498
418537	885.1	1.9	404.4	73038	1850428	1800813	109278	253672	26451
390831	890.3	2.1	404.7	72890	1843252	1793739	108370	251584	26397
363125	895.8	2.2	405.1	72720	1825792	1776394	107424	249408	26334
335419	901.5	2.4	405.5	72521	1828899	1779637	106430	247123	26261
307713	907.6	2.6	406.0	72286	1829452	1780350	105377	244699	26176
280007	913.9	2.9	406.6	72004	1785016	1736106	104281	242177	26073
252301	920.8	3.2	407.3	71661	1741525	1692848	103090	239439	25947
224595	928.5	3.6	408.2	71234	1691495	1643110	101756	236370	25791
196889	937.2	4.1	409.4	70686	1634875	1586864	100254	232916	25591
169182	947.3	4.7	410.9	69959	1570761	1523156	98500	228880	25325
141476	959.6	5.7	413.0	68946	1497471	1450646	96358	223954	24955
113770	975.8	7.1	416.2	67441	1412238	1366440	93552	217500	24404
111509	977.4	7.2	416.6	67285	1404615	1358924	93282	216879	24347
109247	979.0	7.3	416.9	67123	1396880	1351300	93004	216239	24288

TABLE 3.3.1.5.2

**ET LO₂ DEPLETION SEQUENCE
(INCLUDES PRESSURANT) - Continued**

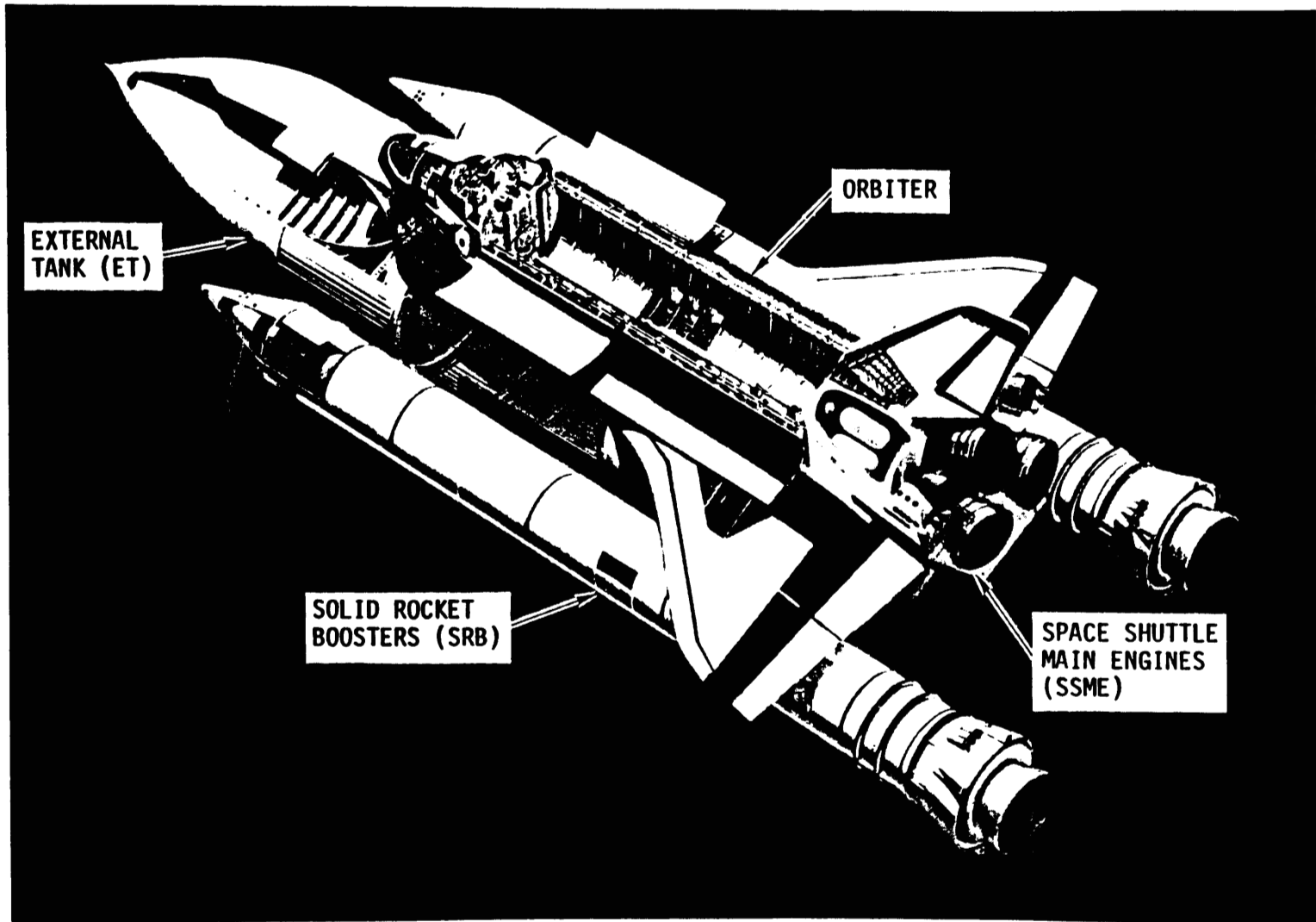
WT (LB)	CENTER-OF-GRAVITY(IN)			MOMENTS OF INERTIA (SLUG-FT ²)			PRODUCTS OF INERTIA (SLUG-FT ²)		
	X	Y	Z	IXX	IYY	IZZ	PXY	PXZ	PYZ
106985	980.7	7.5	417.3	66953	1389024	1343559	92717	215579	24226
104723	982.4	7.7	417.6	66777	1381040	1335695	92421	214897	24162
102462	984.2	7.8	418.0	66593	1372918	1327699	92114	214192	24094
100200	986.0	8.0	418.4	66400	1364652	1319565	91797	213461	24024
97938	987.9	8.2	418.8	66198	1356233	1311283	91467	212702	23950
95677	989.9	8.4	419.3	65987	1347652	1302845	91125	211915	23873
93415	991.9	8.6	419.8	65776	1338901	1294246	90768	211096	23792
91153	994.1	8.8	420.3	65534	1329974	1285477	90398	210244	23707
88891	996.3	9.0	420.8	65290	1320862	1276531	90012	209356	23618
86630	998.6	9.3	421.3	65033	1311558	1267403	89610	208431	23524
84368	1001.0	9.5	421.9	64762	1302055	1258084	89190	207465	23425
82106	1003.6	9.8	422.5	64477	1292345	1248569	88752	206457	23321
79845	1006.2	10.1	423.1	64175	1282419	1238849	88294	205403	23210
77583	1009.0	10.3	423.8	63856	1272268	1228915	87814	204301	23094
75321	1011.9	10.7	424.5	63517	1261879	1218758	87312	203146	22970
73059	1014.9	11.0	425.3	63158	1251239	1208363	86785	201934	22838
70798	1018.1	11.3	426.1	62776	1240330	1197715	86232	200661	22699
68536	1021.5	11.7	426.9	62368	1229131	1186794	85649	199319	22550
66274	1025.0	12.1	427.9	61933	1217615	1175575	85033	197903	22390
64013	1028.8	12.5	428.8	61467	1205752	1164029	84381	196404	22220
61751	1032.8	13.0	429.9	60966	1193503	1152121	83689	194812	22037
59489	1037.1	13.5	431.0	60428	1180824	1139810	82951	193116	21840
57227	1041.6	14.0	432.3	59847	1167666	1127048	82163	191302	21628
54966	1046.5	14.6	433.6	59218	1153968	1113779	81317	189356	21398
52704	1051.7	15.2	435.0	58536	1139665	1099941	80406	187260	21148

TABLE 3.3.1.5.2

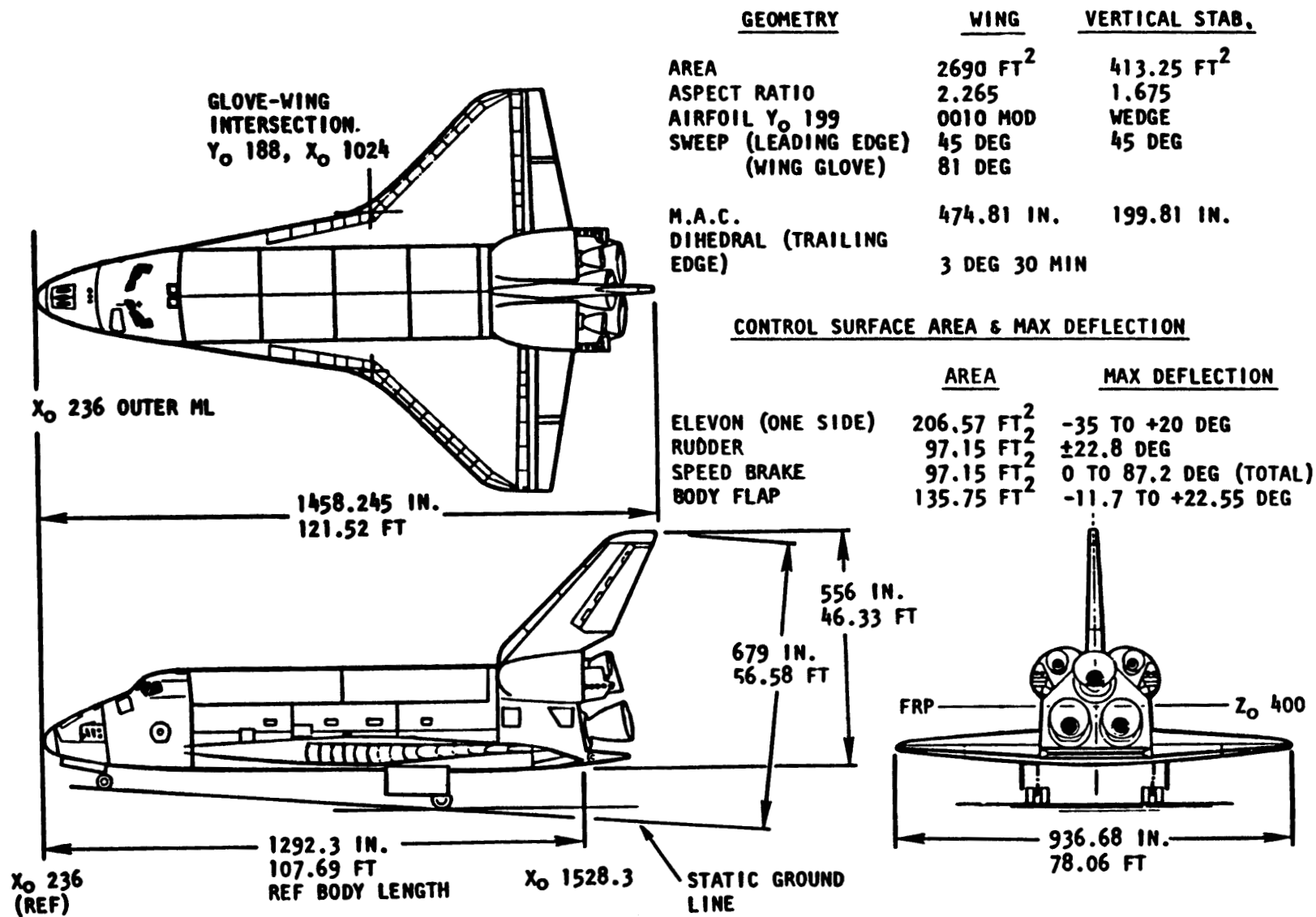
**ET LO₂ DEPLETION SEQUENCE
(INCLUDES PRESSURANT) - Concluded**

WT (LB)	CENTER-OF-GRAVITY(IN)			MOMENTS OF INERTIA (SLUG-FT ²)			PRODUCTS OF INERTIA (SLUG-FT ²)		
	X	Y	Z	IXX	IYY	IZZ	PXY	PXZ	PYZ
50442	1057.4	15.9	436.6	57792	1124680	1085464	79421	184995	20876
48180	1063.8	16.7	438.3	56978	1108930	1070269	78352	182535	20579
45919	1070.3	17.5	440.2	56084	1092317	1054266	77187	179855	20252
43657	1077.7	18.4	442.3	55097	1074731	1037352	75912	176923	19891
41395	1085.8	19.4	444.6	54003	1056040	1019408	74510	173699	19491
39134	1094.7	20.5	447.2	52782	1036091	1000291	72962	170138	19045
36872	1104.7	21.8	450.1	51412	1014688	979823	71241	166180	18543
34610	1115.8	23.2	453.3	49862	991585	957777	69316	161753	17977
32348	1128.3	24.8	457.1	48095	966459	933856	67146	156761	17331
30087	1142.6	26.7	461.4	46063	938876	907659	64675	151077	16588
27825	1159.0	28.8	466.3	43701	908246	878640	61830	144533	15724
25563	1178.2	31.4	472.2	40921	873757	846048	58511	136898	14708
23302	1200.9	34.4	479.2	37601	834284	808840	54578	127853	13494
21040	1228.2	38.1	487.7	33567	788263	765570	49837	116947	12019
18778	1261.9	42.7	498.3	28561	733507	714228	44007	103537	10188
16516	1304.2	48.6	511.8	22184	666931	652001	36674	86671	7857
14255	1324.5	52.6	521.0	13949	564096	554582	25709	59135	5100
11993	1384.5	50.0	515.0	13264	592753	583707	28237	64950	4850
9731	1416.9	46.2	506.3	12260	612599	604237	29605	68095	4483
7469	1395.8	40.2	492.4	10648	599209	591946	28756	66144	3893
5208	1255.7	26.8	466.2	7636	485730	480521	22806	52456	2792
2946	714.7	0.0	400.0	0	5	4	0	1	0

FIGURE 3-1
SPACE SHUTTLE VEHICLE



**FIGURE 3-2
ORBITER VEHICLE DIMENSIONS**



**FIGURE 3-3
EXTERNAL TANK**

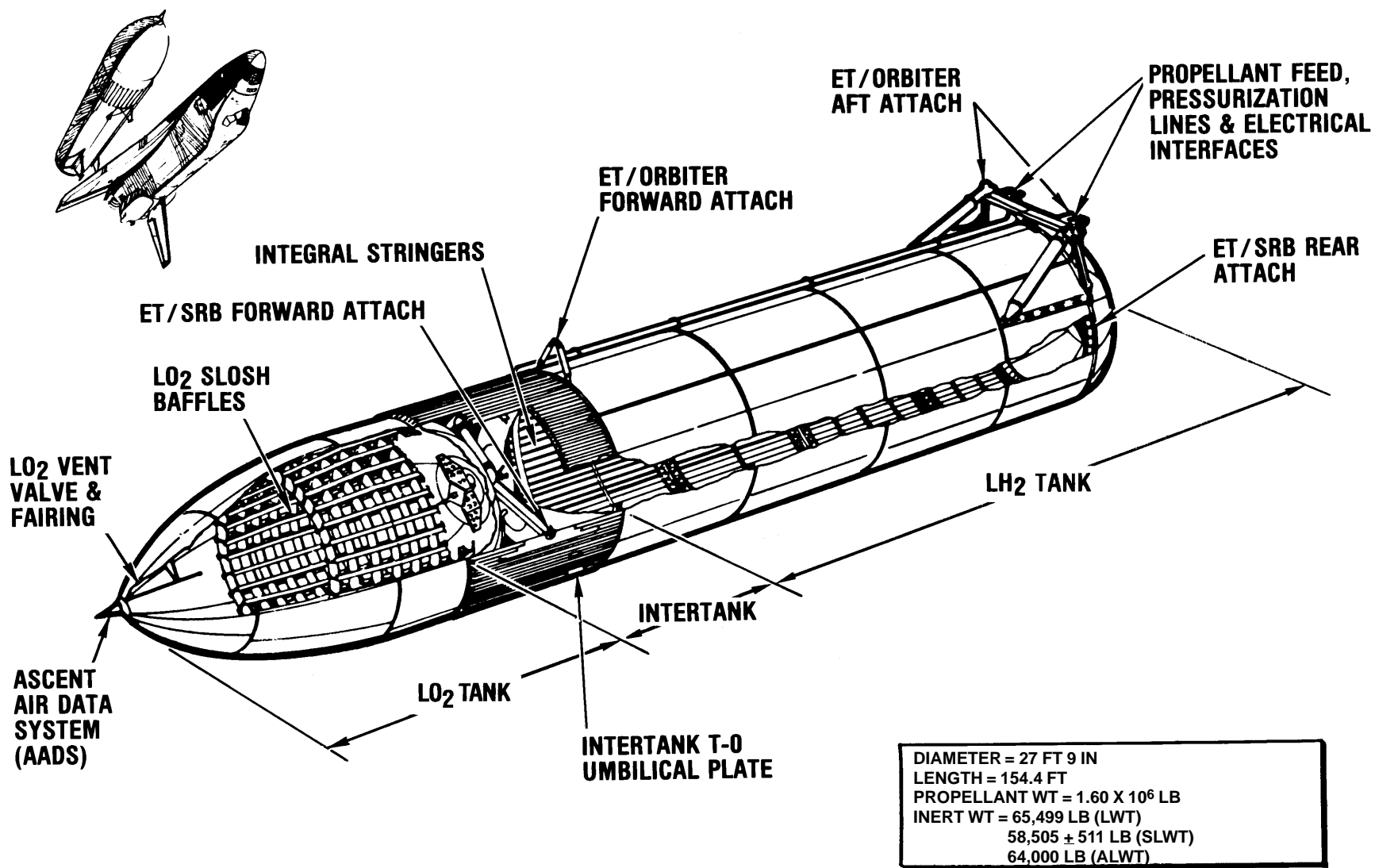


FIGURE 3.3.1.3-1

THREE AND FOUR BAFFLE LO₂ DAMPING CURVES

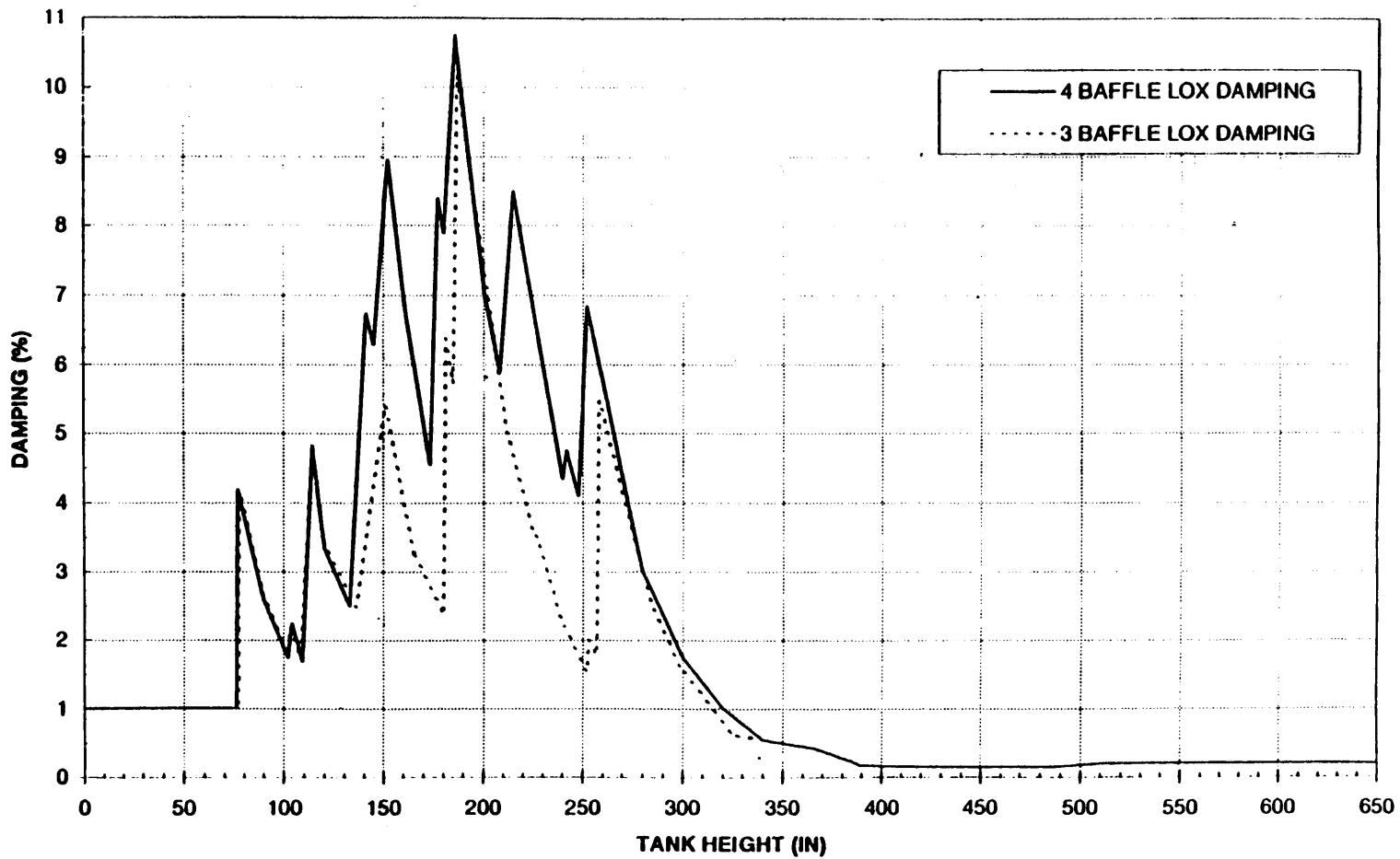


FIGURE 3.3.1.3-2

LWT AND SLWT LH₂ DAMPING CURVES

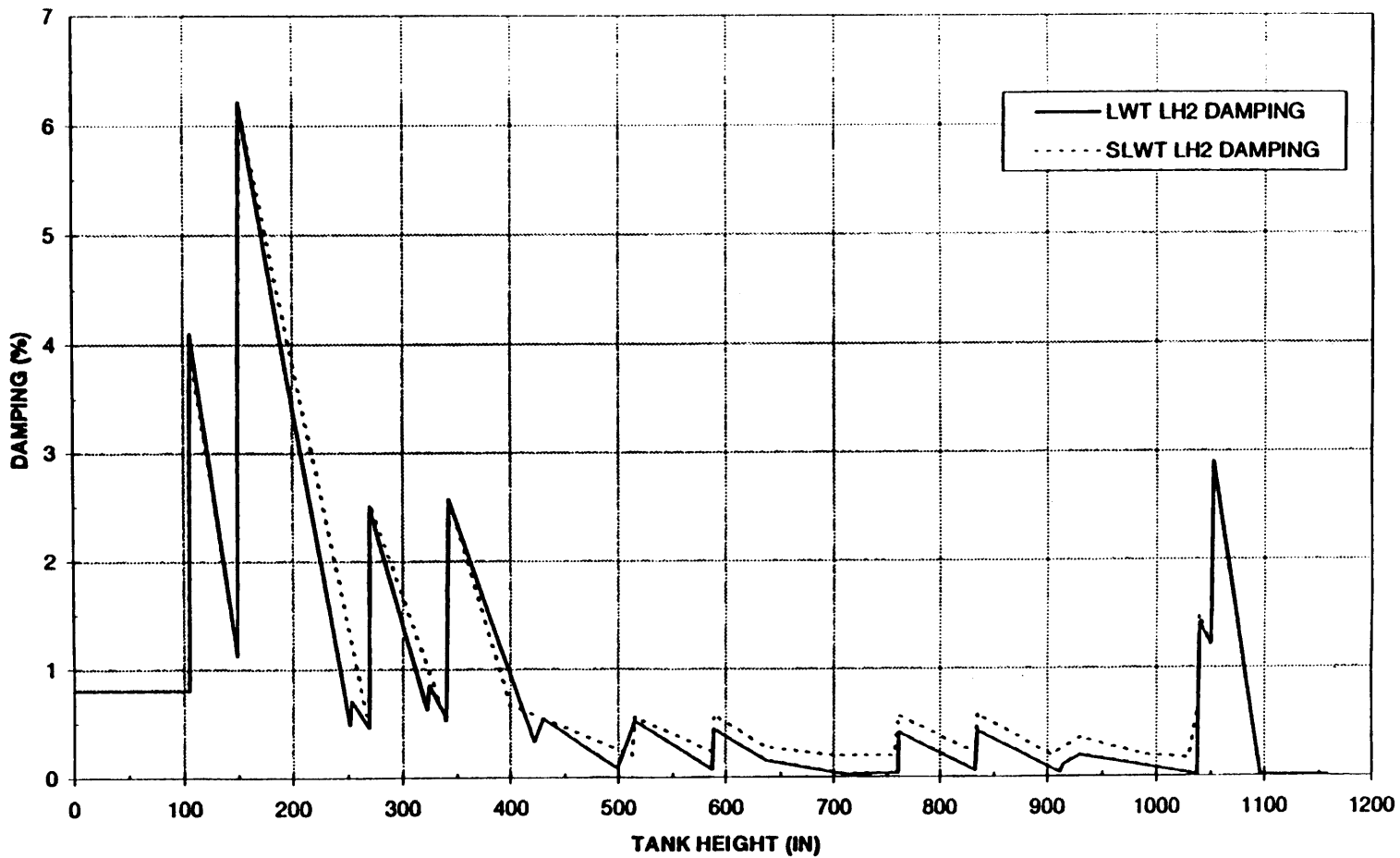


FIGURE 3.3.1.4-1

SLOSH MODEL: SPRING-MASS-DAMPER ANALOGY

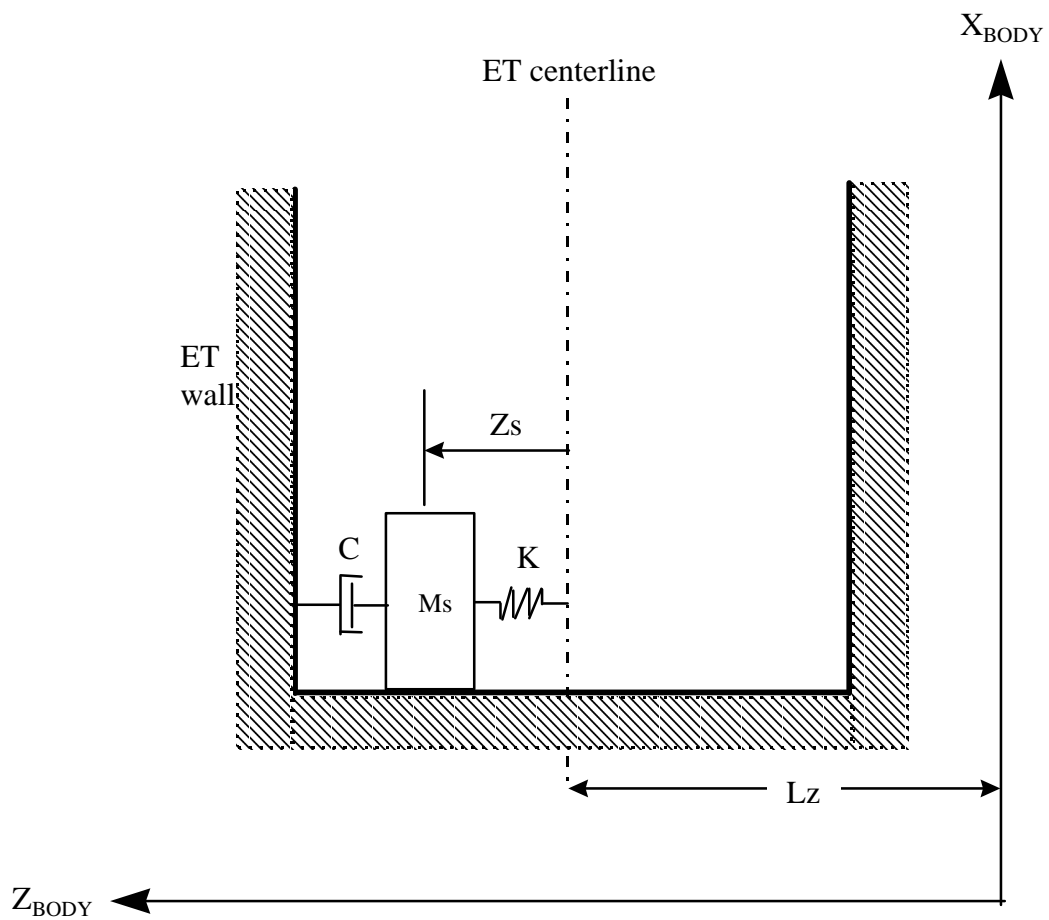


FIGURE 3.3.1.4-2

COORDINATE SYSTEM FOR SLOSH EQUATION DERIVATION

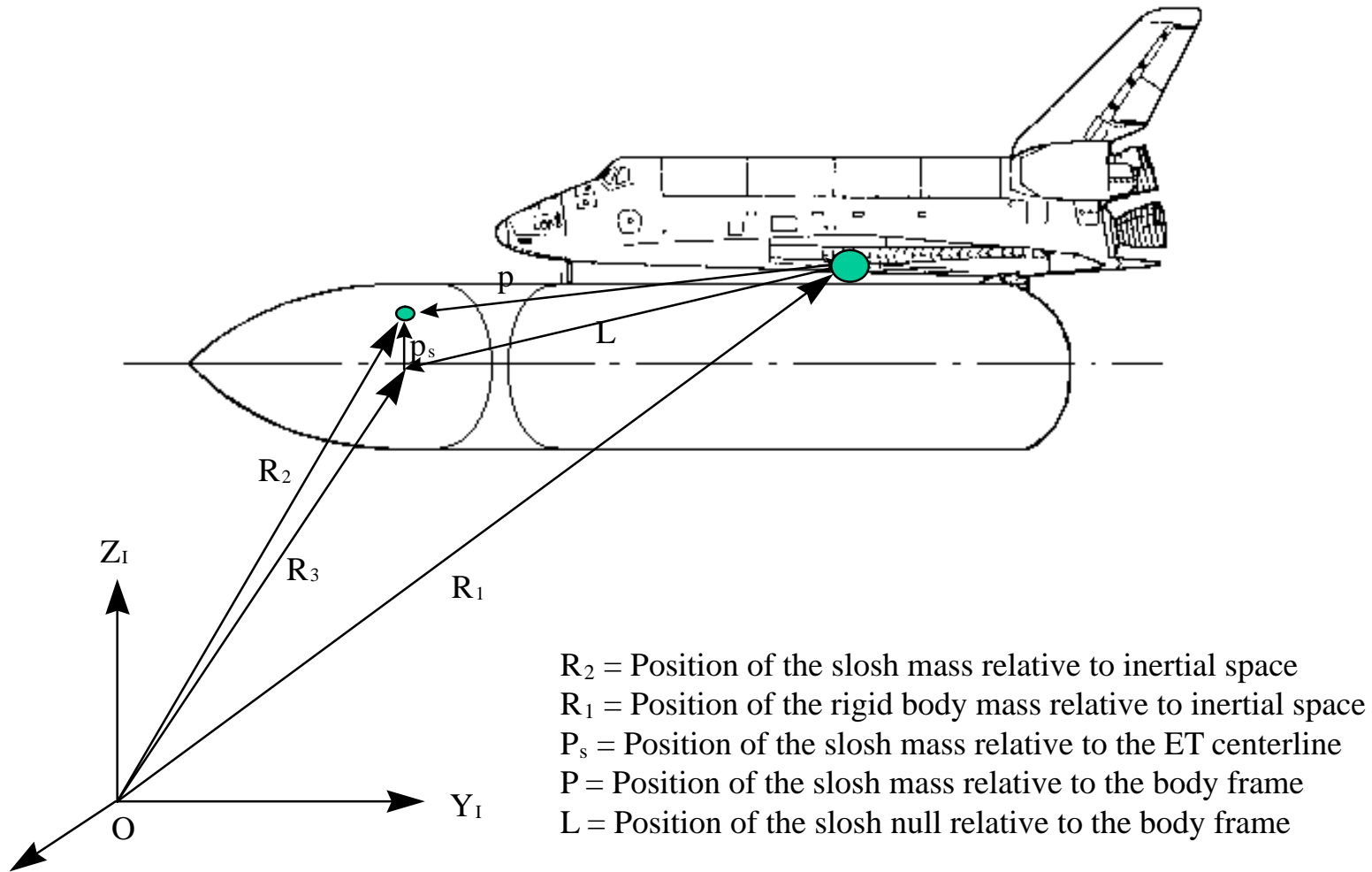


FIGURE 3.3.1.4-3

LIQUID OXYGEN AND HYDROGEN SLOSH CONFIGURATION

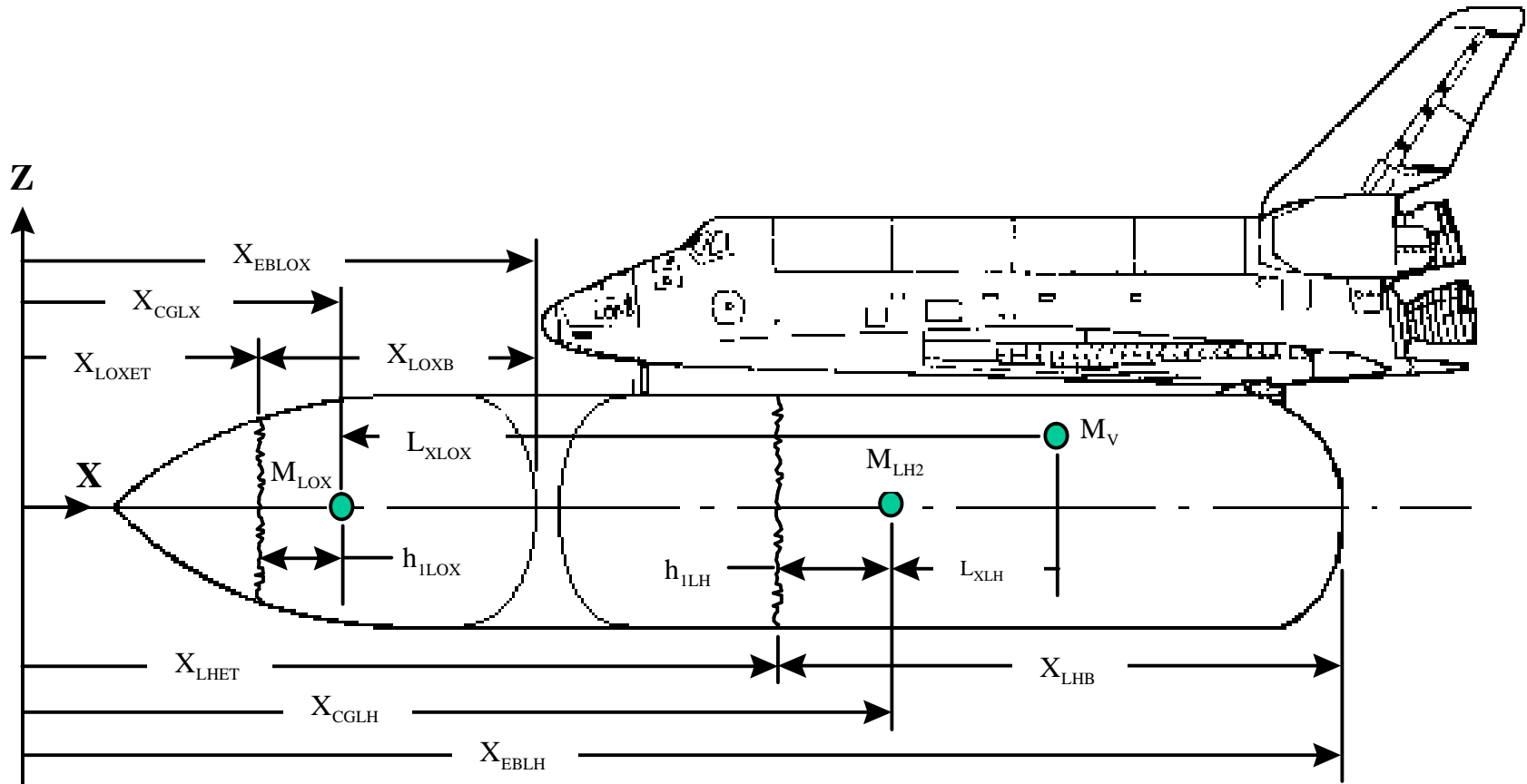
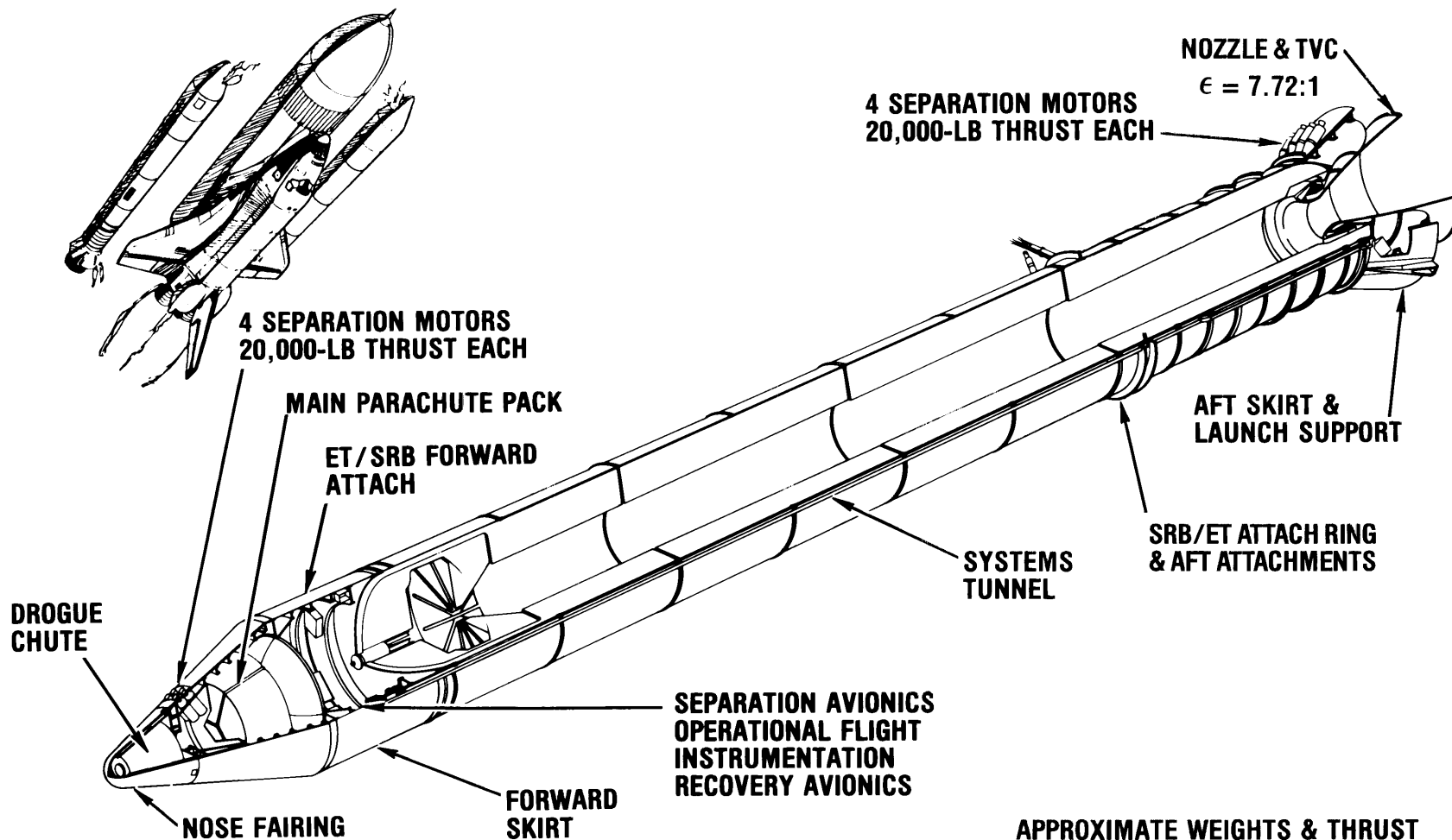


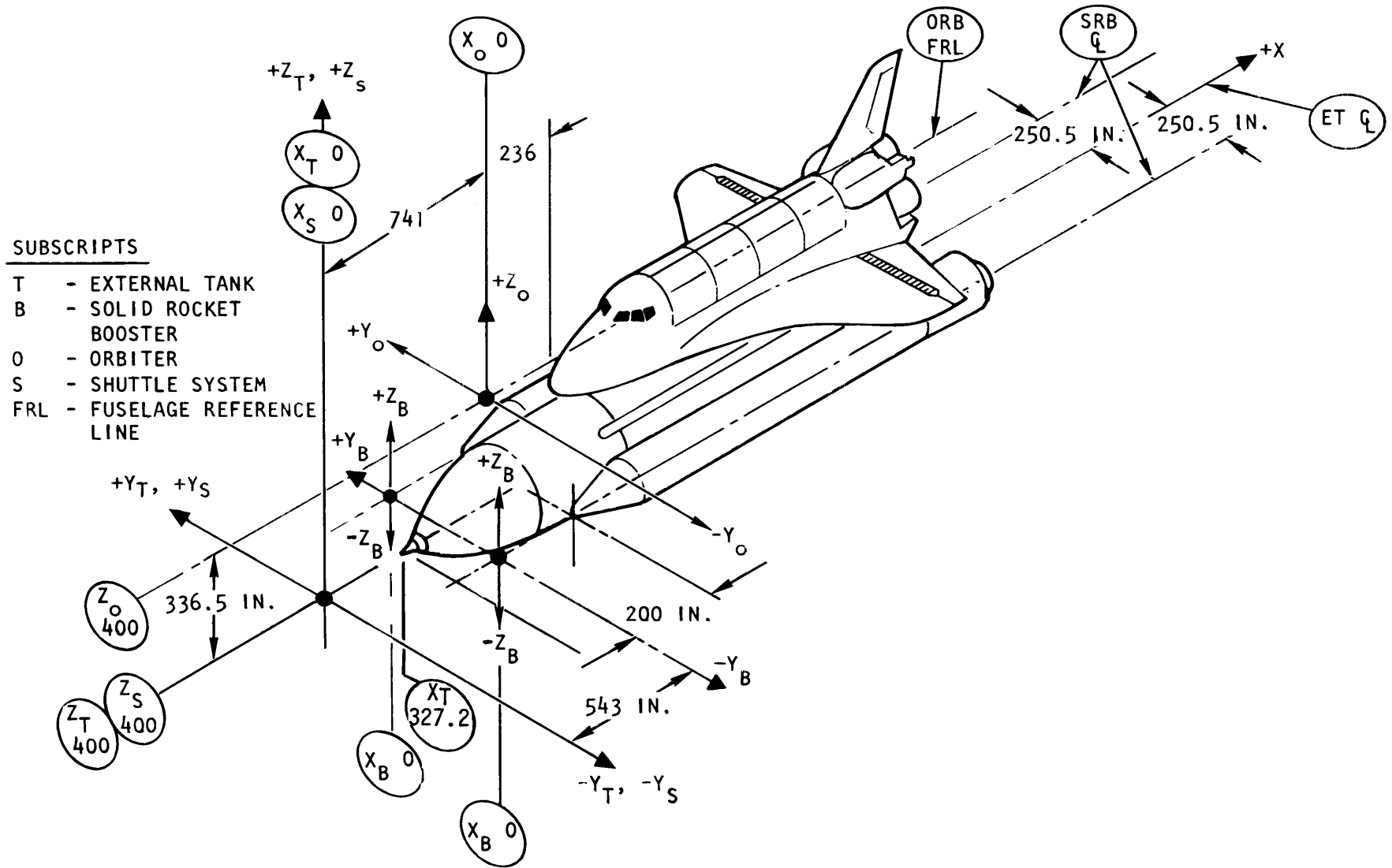
FIGURE 3-4
SOLID ROCKET BOOSTER



DIMENSIONS	
LENGTH	1790 IN.
DIAMETER	146 IN.

APPROXIMATE WEIGHTS & THRUST	
GROSS WEIGHT	1,301,300 LB
INERT WT	192,100 LB
THRUST (SL)	2.65M LB

FIGURE 3-5
SHUTTLE COORDINATE SYSTEM



SUBSCRIPTS

- T - EXTERNAL TANK
- B - SOLID ROCKET BOOSTER
- O - ORBITER
- S - SHUTTLE SYSTEM
- FRL - FUSELAGE REFERENCE LINE

FIGURE 3-6
SPACE SHUTTLE VEHICLE DIMENSIONS

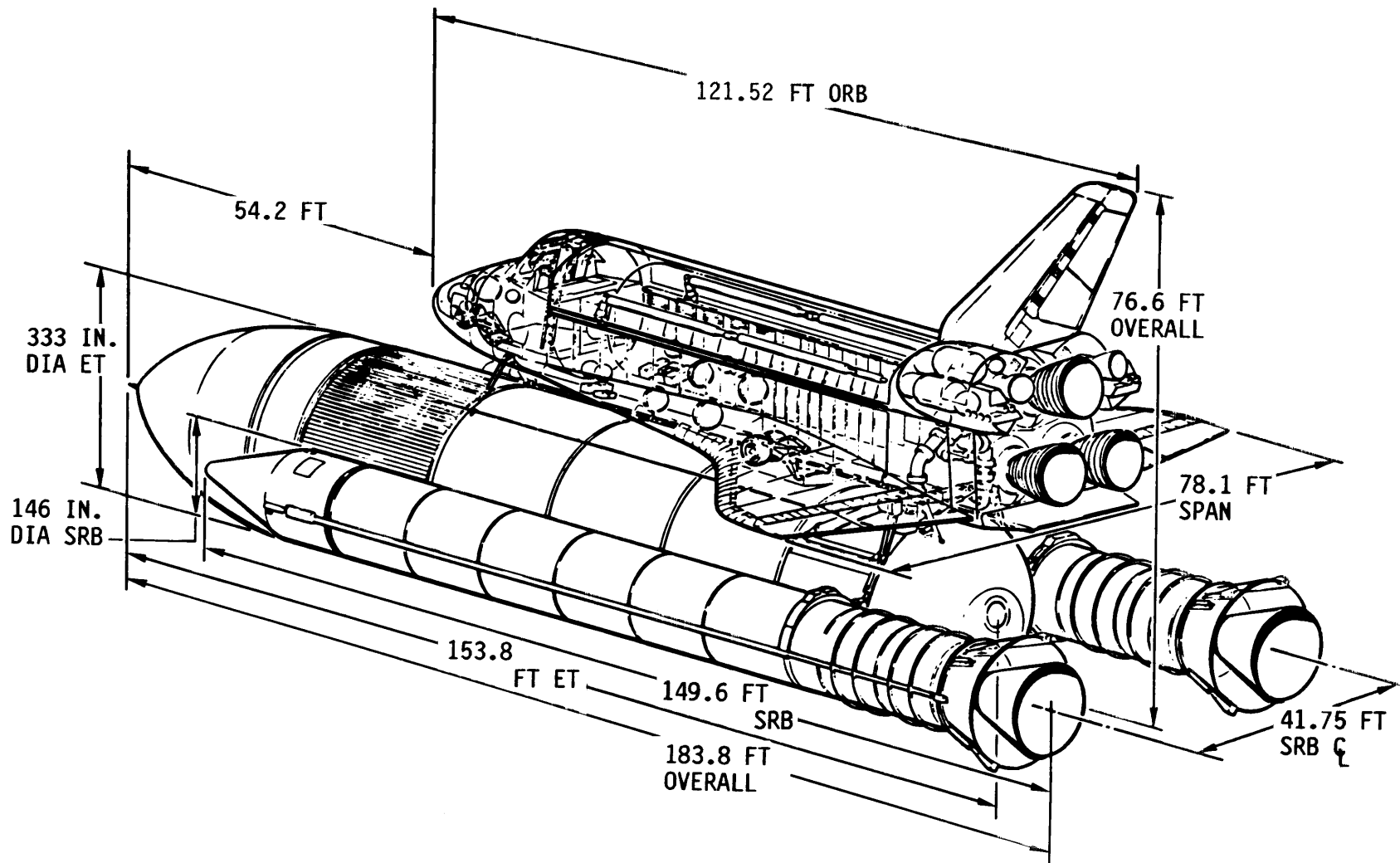
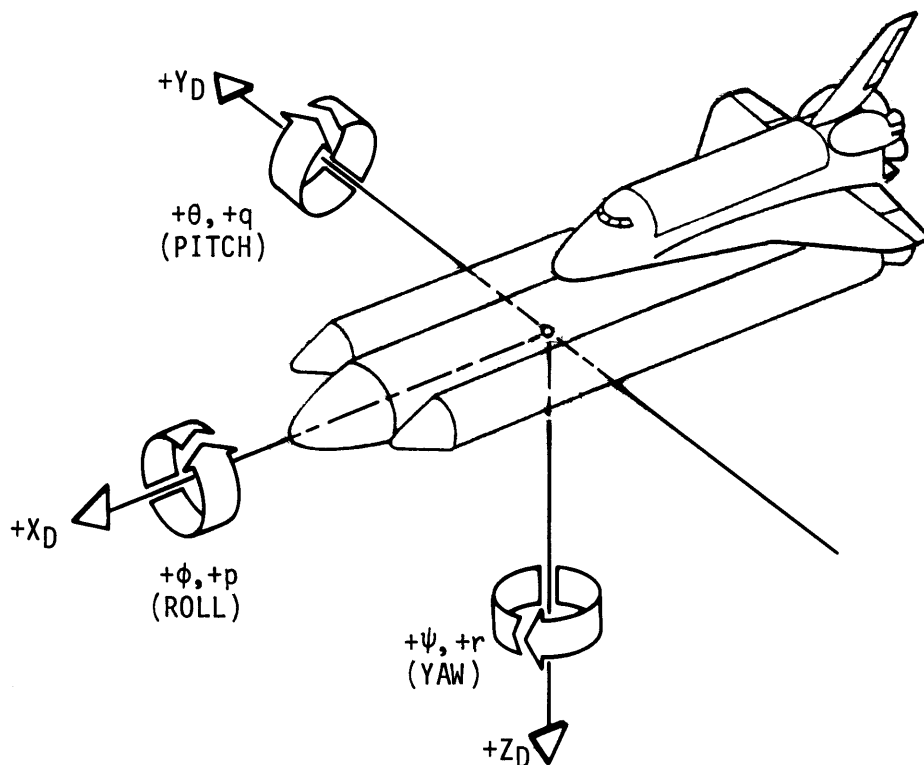


FIGURE 3-7

SHUTTLE SYSTEM DYNAMIC BODY AXES



CAUSE

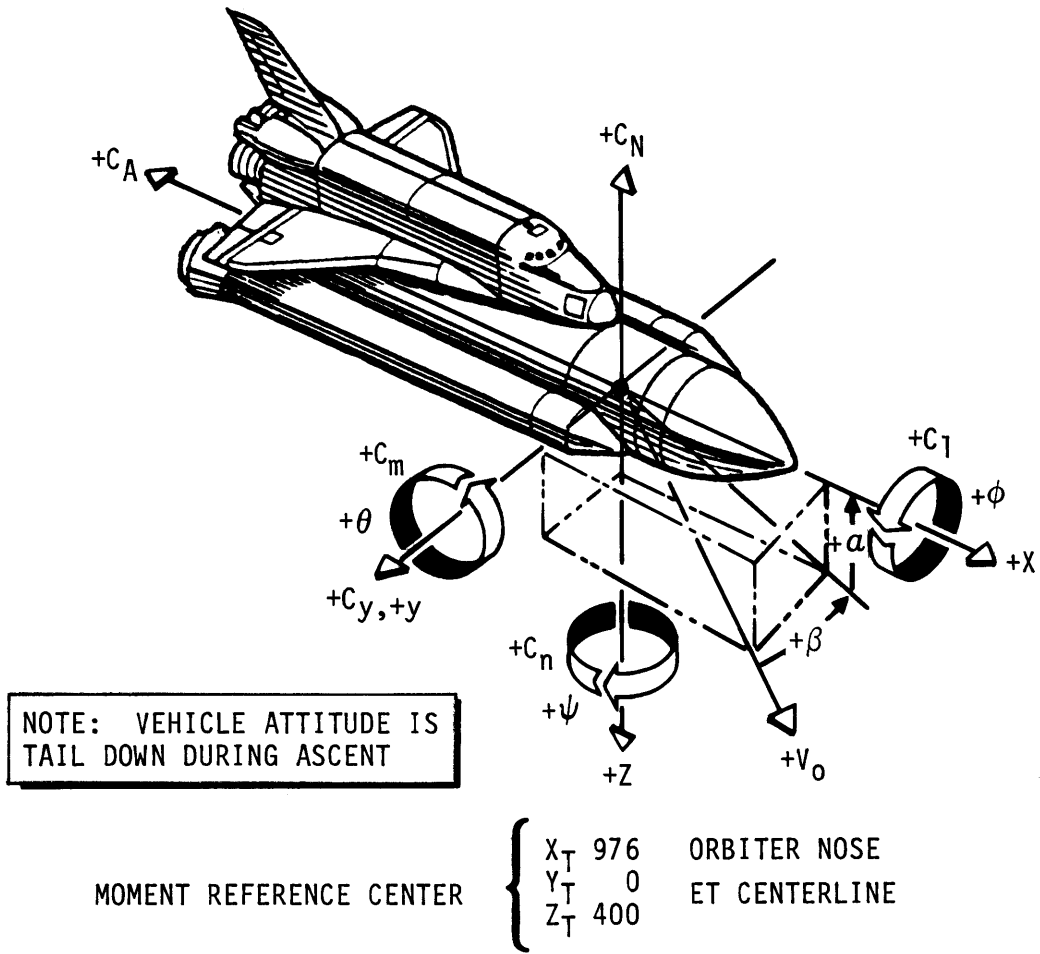
EFFECT

- + ANGLE OF ATTACK (+ α)
- + ANGLE OF SIDESLIP (+ β)
- + ELEVON DEFLECTION (+ δ_e)
- + GIMBAL DEFLECTION (PITCH)
- + GIMBAL DEFLECTION (YAW)
- + FORCE
- + MOMENT
- + ACCELERATION
- + LOAD FACTOR
- + ANGULAR ACCELERATION
- + VELOCITY

- Z AIRLOAD
- Y AIRLOAD
- Z ELEVON FORCE
- Z THRUST FORCE
- + Y THRUST FORCE
- + ACCELERATION AND + LOAD FACTOR
- + ANGULAR ACCELERATION
- + VELOCITY
- INERTIA FORCE
- INERTIAL MOMENT
- + DISPLACEMENT
- WHEN INTEGRATING FROM NOSE TO TAIL
- + SHEAR
- + BENDING MOMENT ABOUT Z-AXIS
- BENDING MOMENT ABOUT Y-AXIS
- + TORSIONAL MOMENT

- + FORCE
- + Y SHEAR
- + Z SHEAR
- + TORQUE

FIGURE 3-8
AERODYNAMIC BODY-AXIS REFERENCE SYSTEM



THIS PAGE INTENTIONALLY LEFT BLANK