4.0 MASS PROPERTIES AND PROPELLANT LOADING

The element and integrated mass properties of the Space Shuttle Vehicle on a mission-to-mission basis are documented in NSTS 09095, Space Shuttle Systems Weight and Performance Status Report and NSTS 08934, Volume II, Space Shuttle Operational Databook, Volume II, Mission Mass Properties. The database that generates NSTS 09095 is also used to generate Mass Properties for all of the TDDP used for ascent simulations. The Shuttle Operational Data Book (SODB) is used to capture the projected, end-of-mission consumable and mass property baseline used for various purposes, including verification of Orbiter entry constraints and establishing the total vehicle inert weight at landing.

This section provides additional, more general, information.

4.1 ELEMENT INERT WEIGHTS

The inert weights of the Space Shuttle elements (Orbiter, SSME, ET, SRB) are specified in the current issue of NSTS 09095.

4.2 CREW COMPARTMENT

Standard crew compartment mass properties for various man/day configurations are listed in the current issue of NSTS 09095.

4.3 WEIGHT ALLOWANCE FOR ICE

There shall be no weight allowance for acreage ice formation on the ET. The ice within the intertank will be considered. Water in the ET Thermal Protection System (TPS) is also considered.

4.4 PROPELLANT LOADING

4.4.1 Main Propulsion System (MPS)

The MPS propellants consist of those propellants loaded in the ET, Orbiter feedlines, and SSMEs. The dominant parameters affecting a MPS propellant inventory are the propellant load, Mixture Ratio (MR) and fuel bias.

The propellant load is controlled by sensor height (controlling volume of propellant loaded), ullage pressure and atmospheric pressure. The sensor height is fixed at a maximum load that provides the minimum ullage volume for propellant load control. For both LWTs and SLWTs, the LH_2 100% sensors are located at XT 1044.6 and the LO_2 100% sensors are located at XT 412.58. The ullage pressure is dependent upon ET ventvalve stroke limiter - the larger the stroke limiter the larger the vent, the lower the pressure the higher the density. All ETs now have a 1.1-inch stroke limiter.

The propellant inventories are based on the conditions and assumptions specified in Table 4.1. Shown are the usable propellant (available) for impulse, the required reserves (fuel bias, Flight Performance Reserve [FPR]), trapped and that used as pressurants. The upper half of the load sheet defines the propellant loaded, and propellant onboard at Engine Start Command (ESC) and SRB ignition command by element. It is to be noted MR was flight derived from reconstruction data.

The SPAD baseline propellant inventories used for STS-26 and subsequent flights are listed in Table 4.1.1. The “MARGINS” program’s inputs for the LWT and the SLWT inventories, are listed in Tables 4.1.2 and 4.1.3, respectively. All of the historical MPS propellant inventories created for use since STS-26 are contained in Appendix G, whereas only the current inventories are retained in this volume (Tables 4.95 through 4.115).

The use of a MR other than 6.0 is an operational constraint dependent upon propellant load and fuel bias. The fuel bias is dependent upon trajectory design philosophy. Three design philosophies are as follows:

1. Optimum performance
2. Equal probability of LO_2 and LH_2 Low-level Cutoff (LLCO)
3. Specific probability of LLCO

The current trajectory design philosophy is optimum performance, that is minimum summation of fuel bias and FPR using the equations specified in Table 4.1. The usable impulse that can be consumed at the Over Board MR (OBMR) is the propellant loaded, modified by the propellant used for fuel bias, thrust buildup and shutdown, trapped propellants, propellants used as pressurants, and propellants vented after valve closure.

The FPR is the flight performance reserves allocation for $+3$-sigma systems dispersions for nominal and Return to Launch Site (RTLS), $+2$-sigma for Abort Once Around/Transoceanic Abort Landing (AOA/TAL). The fuel bias is determined by ET propellant load and SSME MR.

The usable propellant for a mission is determined within the constraints of ullage volumes, ullage pressure, densities, atmospheric pressure, MR, fuel bias, and propellant residuals.

The inputs required to properly run the MPS propellant loading prediction computer program, PLOAD, have been gathered in several tables. Tanking tables relate tank volumes to vertical position within the tank. The PLOAD key data is associated with the sensors between the 98% location and the overfill sensor. The tank volumes, under cryogenic conditions, for the key level sensors at the tops of the LO_2 and LH_2 tanks, for LWT-68 and subs, are listed in Table 4.1.4. The data are listed at four values of ullage pressure (psig). The same type of data for SLWT-01 and subs are in Table 4.1.5.

During stable replenish, tank LO_2 ullage pressure decays with time. This decay has been modeled by three (3) 4th degree curve fit equations. The coefficients of these equations are listed in Table 4.1.6.

Extensive tests were conducted on the Main Propulsion Test Article at the Stennis Space Center, National Space Technology Laboratory in the late 70's, early 80's. These tests used data from the National Bureau of Standards to correlate tank ullage pressures to bulk propellant densities and temperatures (average conditions at the centroid location) for Shuttle Program ETs. For various GH_2 ullage pressures (psia), the LH_2 bulk densities and temperatures are listed in Table 4.1.7. The vented values apply to conditions at the End of Replenish (EOR). The pressurized values are the corresponding conditions at ESC, when the tank has been pressurized for flight. Similar data for GO_2 ullage pressures (psia) and LO_2 bulk densities and temperatures are listed in Table 4.1.8.

Several inputs to the PLOAD program are found in various tables in this document. They are identified for the LWT and SLWT in Table 4.1.9.

The propellants internal to the SSMEs are:

The propellants internal to the SSMEs are:

SSME $\times$ 3 propellants (lb)	LH_2	LO_2	Total
Dry	0	0	0
Prestart	58	1325	1383
Operating	116	1497	1613
Burnout	58	1325	1383

While the propellant inventories quantify the propellant contained in the Orbiter and SSMEs up to MECO, they do not cover what happens to that propellant during the SSME shutdown sequence or the MPS propellant dump sequences. As there are different software procedures depending on the trajectory being flown, post MECO propellant data has been broken down into four tables: Table 4.1.10 for the nominal (normal, no-fail) trajectory; Table 4.1.11 for the AOA/Abort to Orbit (ATO) (one engine out) trajectory; Table 4.1.12 for the TAL (one engine out) trajectory; and Table 4.1.13 for the RTLS (one engine out) trajectory. These tables are based on the CMMD, CMM-0067, CMM-00167, and CMM-00198. The process for implementing the data in these tables into ascent GN&C simulations is described in Paragraph 10.7.1, Mass properties - MECO Command through MPS Dump.

4.4.2 Orbital Maneuvering System (OMS)

The OMS propellant loading requirements are specified in NSTS 09095 and NSTS 08934, Volume II. The minimum propellant load in the OMS tanks at launch is 2038 pounds of fuel and 3,362 pounds of oxidizer per pod. The propellant required consists of the amount for nominal mission maneuvers plus an additional amount to satisfy a V = 250 feet per second (fps) requirements.

4.4.3 Reaction Control System (RCS)

The RCS propellant loading data are specified in NSTS 09095 and NSTS 08934, Volume II.

TABLE 4.1

BASELINE PROPELLANT INVENTORIES - NOMINAL

The propellant inventories are based on the following conditions and assumptions

1	ET effective volume at 100% sensor (cryo, vented) Effective volume = tank volume below sensor - bubble volume
2	Volumes are taken from the current MMC tanking tables for lightweight ETs (LWT-7 and subsequent). LWT-7 and subsequent do not include an LO_2 antigeyser line. The volumes of these tables have been modified for changes due to height of load and ullage pressure.
3	Propellant densities and bulk temperatures were calculated by a semiemperical method developed jointly by NASA MSFC, Rockwell ST&SG, and MMC.
4	EMR over the time interval between SRB ignition and MECO is the ratio of oxidizer/fuel supplied to the engine inlets. It includes propellants burned by the engines as well as propellants bled from the engines for use in pressurizing the propellant tanks. EMR is given by the relation: $$EMR = \frac{(LO_{2ESC}) - (LO_{2BU}) - (LO_{2LR}) - (LO_{2SD}) - (LO_{2VT})}{(LH_{2ESC}) - (FB) - (LH_{2BU}) - (LH_{2LR}) - (LH_{2SD}) - (LH_{2VT})}$$ where EMR = Engine mixture ratio (oxidizer/fuel) ESC = Quantity loaded at engine start command, total (lb_m) BU = Quantity consumed during SSME thrust buildup and SRB ignition delay (lb_m) LR = Unusable liquid residuals, total (lb_m) SD = Quantity consumed during shutdown, total (lb_m) VT = Quantity vented after SSME valve closure (lb_m) FB = Fuel bias (lb_m)
5	OBMR is the ratio of oxidizer/fuel burned by the engines. It does not include propellants supplied to the engines but used to pressurize the propellant tanks. OBMR is given by the relation: $$OBMR = \frac{(LO_{2ESC}) - (LO_{2BU}) - (LO_{2LR}) - (LO_{2PR}) - (LO_{2SD}) - (LO_{2VT})}{(LH_{2ESC}) - (FB) - (LH_{2BU}) - (LH_{2LR}) - (LH_{2PR}) - (LH_{2SD}) - (LH_{2VT})}$$ where OBMR = Overboard mixture ratio (oxidizer/fuel) PR = Quantity used for tank pressurization (lb_m) All other items are as defined above.

TABLE 4.1

BASELINE PROPELLANT INVENTORIES - NOMINAL - Concluded

<table>
<tr><td>6</td><td>The LO_2 drainback mass and drainback initiation time, OTR, depend on the initial loading level as follows:

LO_2 Sensor (%)	X_T (in)	DB Mass (lb_m)	Initiate DB (sec)
100+	409.48	7,190	−354
100	412.58	5,959	−295
100−	415.48	4,717	−235

Drainback mass and drainback initiation time are related by the equation:

$$OTR = -\left[295 + \frac{(WDB - 5,959)}{20.83}\right]$$

where:

OTR = Oxidizer terminate replenish time (seconds)
(Note that OTR is a negative number and that the nominal start of drainback is 5 seconds after OTR)

WDB = Desired drainback mass (lb_m)</td></tr>
<tr><td>7</td><td>The thrust buildup propellant loss (three SSMEs) is the propellant consumed during the 2.716-second delay for SRB start.</td></tr>
<tr><td>8</td><td>The Rated Power Level (RPL) for the SSMEs corresponds to an engine thrust of 470,000 lb_f. Other engine power settings are referenced to this value: e.g., Minimum Power Level (MPL) is 65% RPL and Full Power Level (FPL) is 109% RPL.</td></tr>
</table>

TABLE 4.1.1

PROPELLANT INVENTORY REVISIONS VERSUS STS FLIGHTS

FLIGHT	INV. REV.	TABLES	REASON FOR CHANGES
STS-26R	G	4.2 to 4.7	1.1 Inch Stroke Limiter and Flight-specific FPR
STS-27R	A	4.8 to 4.13	Flight-derived FPR and Updated Tank Volumes
STS-29	11SL	4.8 to 4.13	Flight-derived FPR and Updated Tank Volumes
STS-30R	11SL	4.8 to 4.13	Flight-derived FPR and Updated Tank Volumes
STS-34	11SL	4.8 to 4.13	Flight-derived FPR and Updated Tank Volumes
STS-33R	11SL	4.8 to 4.13	Flight-derived FPR and Updated Tank Volumes
STS-32R	11SL	4.8 to 4.13	Flight-derived FPR and Updated Tank Volumes
STS-36	AA	4.14 to 4.19	LO_2 Drainback Increased from 5,640 to 5,800 lb_m
STS-31R	AA	4.14 to 4.19	LO_2 Drainback Increased from 5,640 to 5,800 lb_m
STS-41	AA	4.14 to 4.19	LO_2 Drainback Increased from 5,640 to 5,800 lb_m
STS-38	BB	4.20 to 4.25	ET-40 & subs, Vented U11 Press Increased from 0.76 to 0.78 psi, Nose Cone ΔP decrease from 0.03 to 0.01 psi
STS-35	AA	4.14 to 4.19	LO_2 Drainback Increased from 5,640 to 5,800 lb_m
STS-37	AA	4.14 to 4.19	LO_2 Drainback Increased from 5,640 to 5,800 lb_m
STS-39	BB	4.20 to 4.25	ET-40 & subs, Vented U11 Press Increased from 0.76 to 0.78 psi, Nose Cone ΔP decrease from 0.03 to 0.01 psi
STS-40	CC	4.26 to 4.31	S/D power level changed to 67% RPL
STS-43	BB	4.20 to 4.25	ET-40 & subs, Vented U11 Press Increased from 0.76 to 0.78 psi, Nose Cone ΔP decrease from 0.03 to 0.01 psi
STS-48	CC	4.26 to 4.31	S/D power level changed to 67% RPL
STS-44	PP12	4.26 to 4.31	S/D PL changed to 67% RPL, 12 Plugged LO_2 Post
STS-42	PP14	4.26 to 4.31	S/D PL changed to 67% RPL, 14 Plugged LO_2 Post
STS-45	CC	4.26 to 4.31	S/D power level changed to 67% RPL
STS-49	CC	4.26 to 4.31	S/D power level changed to 67% RPL
STS-50	CC	4.26 to 4.31	S/D power level changed to 67% RPL
STS-46	CC	4.26 to 4.31	S/D power level changed to 67% RPL
STS-47	CC	4.26 to 4.31	S/D power level changed to 67% RPL
STS-52	CC	4.26 to 4.31	S/D power level changed to 67% RPL

TABLE 4.1.1

PROPELLANT INVENTORY REVISIONS VERSUS STS FLIGHTS - Continued

FLIGHT	INV. REV.	TABLES	REASON FOR CHANGES
STS-53	DD	4.32 to 4.37	Flight-derived FPR, FB, St & S/D Consumption, Pressurants
STS-56	DD	4.32 to 4.37	Flight-derived FPR, FB, St & S/D Consumption, Pressurants
STS-55	DD	4.32 to 4.37	Flight-derived FPR, FB, St & S/D Consumption, Pressurants
STS-57	DD	4.32 to 4.37	Flight-derived FPR, FB, St & S/D Consumption, Pressurants
STS-51	DD	4.32 to 4.37	Flight-derived FPR, FB, St & S/D Consumption, Pressurants
STS-58	DD	4.32 to 4.37	Flight-derived FPR, FB, St & S/D Consumption, Pressurants
STS-61	EE	4.38 to 4.43	FY94 Update, Flight-derived Usages w/compatible FPR & FB
STS-60	EE	4.38 to 4.43	FY94 Update, Flight-derived Usages w/compatible FPR & FB
STS-62	EE	4.38 to 4.43	FY94 Update, Flight-derived Usages w/compatible FPR & FB
STS-59	EE	4.38 to 4.43	FY94 Update, Flight-derived Usages w/compatible FPR & FB
STS-65	EE	4.38 to 4.43	FY94 Update, Flight-derived Usages w/compatible FPR & FB
STS-64	EE	4.38 to 4.43	FY94 Update, Flight-derived Usages w/compatible FPR & FB
STS-68	EE	4.38 to 4.43	FY94 Update, Flight-derived Usages w/compatible FPR & FB
STS-66	EE	4.38 to 4.43	FY94 Update, Flight-derived Usages w/compatible FPR & FB
STS-63	R9501	4.44 to 4.49	FY95 Update, STS-68 Baseline Flight-derived Usages with STS-61 Baseline FPR & FB
STS-67	R9501	4.44 to 4.49	FY95 Update, STS-68 Baseline Flight-derived Usages with STS-61 Baseline FPR & FB
STS-71	R9501	4.44 to 4.49	FY95 Update, STS-68 Baseline Flight-derived Usages with STS-61 Baseline FPR & FB
STS-70	R9501	4.44 to 4.49	FY95 Update, STS-68 Baseline Flight-derived Usages with STS-61 Baseline FPR & FB
STS-69	R9501	4.44 to 4.49	FY95 Update, STS-68 Baseline Flight-derived Usages with STS-61 Baseline FPR & FB

TABLE 4.1.1

PROPELLANT INVENTORY REVISIONS VERSUS STS FLIGHTS - Continued

FLIGHT	INV. REV.	TABLES	REASON FOR CHANGES
STS-73	R9501	4.44 to 4.49	FY95 Update, STS-68 Baseline Flight-derived Usages with STS-61 Baseline FPR & FB
STS-74	R9501	4.44 to 4.49	FY95 Update, STS-68 Baseline Flight-derived Usages with STS-61 Baseline FPR & FB
STS-72	R9501	4.44 to 4.49	FY95 Update, STS-68 Baseline Flight-derived Usages with STS-61 Baseline FPR & FB
STS-75	R9501	4.44 to 4.49	FY95 Update, STS-68 Baseline Flight-derived Usages with STS-61 Baseline FPR & FB
STS-76	R9501	4.44 to 4.49	FY95 Update, STS-68 Baseline Flight-derived Usages with STS-61 Baseline FPR & FB
STS-77	R9601L	4.50 to 4.55	FY96 Update, STS-70 Baseline Flight-derived Usages with STS-70 Baseline FPR & FB, Controller MR of 6.007 & LO_2 ullage pressure of 0.71 psig
STS-78	R9601L	4.50 to 4.55	FY96 Update, STS-70 Baseline Flight-derived Usages with STS-70 Baseline FPR & FB, Controller MR of 6.007 & LO_2 ullage pressure of 0.71 psig
STS-79	R9605L	4.74 to 4.79	FY96 Update, STS-78 Baseline OBMR with STS-70 Baseline FPR & FB, Controller MR of 6.020, LO_2 ullage pressure of 0.71 psig, -500 lb_m LH_2 Load
STS-80	R9701L	4.80 to 4.85	FY97 Update, STS-78 Baseline SSMEs with STS-70 Baseline FPR & FB, Controller MR of 6.032, LO_2 ullage pressure of 0.71 psig, -500 lb_m LH_2 Load
STS-81	R9701L	4.80 to 4.85	FY97 Update, STS-78 Baseline SSMEs with STS-70 Baseline FPR & FB, Controller MR of 6.032, LO_2 ullage pressure of 0.71 psig, -500 lb_m LH_2 Load
STS-82	R9701L	4.80 to 4.85	FY97 Update, STS-78 Baseline SSMEs with STS-70 Baseline FPR & FB, Controller MR of 6.032, LO_2 ullage pressure of 0.71 psig, -500 lb_m LH_2 Load
STS-83	R9701L	4.80 to 4.85	FY97 Update, STS-78 Baseline SSMEs with STS-70 Baseline FPR & FB, Controller MR of 6.032, LO_2 ullage pressure of 0.71 psig, -500 lb_m LH_2 Load
STS-84	R9701L	4.80 to 4.85	FY97 Update, STS-78 Baseline SSMEs with STS-70 Baseline FPR & FB, Controller MR of 6.032, LO_2 ullage pressure of 0.71 psig, -500 lb_m LH_2 Load
STS-94	R9702L	4.86 to 4.91	FY97 Update, STS-78 Baseline SSMEs with STS-70 Baseline FPR & FB, Controller MR of 6.032, LO_2 ullage pressure of 0.60 psig, -500 lb_m LH_2 Load
STS-85	R9702L	4.86 to 4.91	FY97 Update, STS-78 Baseline SSMEs with STS-70 Baseline FPR & FB, Controller MR of 6.032, LO_2 ullage pressure of 0.60 psig, -500 lb_m LH_2 Load

TABLE 4.1.1

PROPELLANT INVENTORY REVISIONS VERSUS STS FLIGHTS - Continued

FLIGHT	INV. REV.	TABLES	REASON FOR CHANGES
STS-86	R9702L	4.86 to 4.91	FY97 Update, STS-78 Baseline SSMEs with STS-70 Baseline FPR & FB, Controller MR of 6.032, LO_2 ullage pressure of 0.60 psig, -500 lb_m LH_2 Load
STS-87	R9801L	4.92 to 4.97	FY98 Update, STS-81 Baseline Dispersions, LWT & FD SSMEs Used for FPR & FB, Controller MR of 6.032, LO_2 ull pr of 0.60 psig, -493 lb_m LH_2 Load
STS-89	R9802L	4.98 to 4.103	FY98 Update, STS-81 Baseline Dispersions, LWT & SPEC SSMEs Used for FPR & FB, Controller MR of 6.032, LO_2 ull pr of 0.60 psig, -493 lb_m LH_2 Load
STS-90	R9801L	4.92 to 4.97	FY98 Update, STS-81 Baseline Dispersions, LWT & FD SSMEs Used for FPR & FB, Controller MR of 6.032, LO_2 ull pr of 0.60 psig, -493 lb_m LH_2 Load
STS-91	R9806S	4.110 to 4.115	FY98 Update, STS-81 Baseline Dispersions, SLWT & SPEC SSMEs Used for FPR & FB, Controller MR of 6.032, LO_2 ull pr of 0.58 psig, -493 lb_m LH_2 Load
STS-95	R9806S	4.110 to 4.115	FY98 Update, STS-81 Baseline Dispersions, SLWT & SPEC SSMEs Used for FPR & FB, Controller MR of 6.032, LO_2 ull pr of 0.58 psig, -493 lb_m LH_2 Load
STS-88	R9806S	4.110 to 4.115	FY98 Update, STS-81 Baseline Dispersions, SLWT & SPEC SSMEs Used for FPR & FB, Controller MR of 6.032, LO_2 ull pr of 0.58 psig, -493 lb_m LH_2 Load
STS-96	R9806S	4.110 to 4.115	FY98 Update, STS-81 Baseline Dispersions, SLWT & SPEC SSMEs Used for FPR & FB, Controller MR of 6.032, LO_2 ull pr of 0.58 psig, -493 lb_m LH_2 Load
STS-93	R9805S	4.104 to 4.109	FY98 Update, STS-81 Baseline Dispersions, SLWT & FD SSMEs Used for FPR & FB, Controller MR of 6.032, LO_2 ull pr of 0.58 psig, -493 lb_m LH_2 Load
STS-103	R9806S	4.110 to 4.115	FY98 Update, STS-81 Baseline Dispersions, SLWT & SPEC SSMEs Used for FPR & FB, Controller MR of 6.032, LO_2 ull pr of 0.58 psig, -493 lb_m LH_2 Load
STS-99	R9802L	4.98 to 4.103	FY98 Update, STS-81 Baseline Dispersions, LWT & SPEC SSMEs Used for FPR & FB, Controller MR of 6.032, LO_2 ull pr of 0.60 psig, -493 lb_m LH_2 Load
STS-101	R9806S	4.110 to 4.115	FY98 Update, STS-81 Baseline Dispersions, SLWT & SPEC SSMEs Used for FPR & FB, Controller MR of 6.032, LO_2 ull pr of 0.58 psig, -493 lb_m LH_2 Load
STS-106	R0004S	4.122 to 4.127	FY00 Update, SLWT, STS-96 Baseline Flight Derived Usage w/ΔIW Collector FPR & FB, Controller MR of 6.032, LO_2 ull pr of 0.79 psig, -459 lb_m LH_2 Load

TABLE 4.1.1

PROPELLANT INVENTORY REVISIONS VERSUS STS FLIGHTS - Concluded

FLIGHT	INV. REV.	TABLES	REASON FOR CHANGES
STS-92	R0004S	4.122 to 4.127	FY00 Update, SLWT, STS-96 Baseline Flight Derived Usage w/ΔIW Collector FPR & FB, Controller MR: 6.032, LO_2 ull pr: 0.79 psig, -459 lb_m LH_2 Load
STS-97	R0004S	4.122 to 4.127	FY00 Update, SLWT, STS-96 Baseline Flight Derived Usage w/ΔIW Collector FPR & FB, Controller MR: 6.032, LO_2 ull pr: 0.79 psig, -459 lb_m LH_2 Load
STS-98	R0004S	4.122 to 4.127	FY00 Update, SLWT, STS-96 Baseline Flight Derived Usage w/ΔIW Collector FPR & FB, Controller MR: 6.032, LO_2 ull pr: 0.79 psig, -459 lb_m LH_2 Load
STS-102	R0004S	4.122 to 4.127	FY00 Update, SLWT, STS-96 Baseline Flight Derived Usage w/ΔIW Collector FPR & FB, Controller MR: 6.032, LO_2 ull pr: 0.79 psig, -459 lb_m LH_2 Load
STS-100	R0004S	4.122 to 4.127	FY00 Update, SLWT, STS-96 Baseline Flight Derived Usage w/ΔIW Collector FPR & FB, Controller MR: 6.032, LO_2 ull pr: 0.79 psig, -459 lb_m LH_2 Load
STS-104	R0004S	4.122 to 4.127	FY00 Update, SLWT, STS-96 Baseline Flight Derived Usage w/ΔIW Collector FPR & FB, Controller MR: 6.032, LO_2 ull pr: 0.79 psig, -459 lb_m LH_2 Load
STS-105	R0104S	4.134 to 4.139	FY01 Update, SLWT, STS-106 Baseline Dispersions and FPR & FB, Controller MR: 6.032, LO_2 ull pr: 0.78 psig, -460 lb_m LH_2 Load

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TABLE 4.1.2

DAY-OF-LAUNCH MARGINS PROGRAM INPUTS (LWT)

MARGINS VARIABLE NAME	DESCRIPTION (SPAD variable name)	UNITS	VALUE
MR	OBMR	n/a	See Table 4.129*
FBIAS	Nominal Fuel Bias (FUEL BIAS)	lb_m	See Table 4.129*
LOXLOD	Load at Engine Start Command, LO_2	lb_m	See Table 4.129*
LH_2LOD	Load at Engine Start Command, LH_2	lb_m	See Table 4.129*
WP	Usable Impulse, Used at OBMR, Total	lb_m	See Table 4.129*
UNMPS	Unusable Propellant for MARGINS UNMPS = <u>UNUSABLE</u> + Fuel Bias (BIAS) + VENTED AFTER SSME VALVE CLOSURE Note: Use TOTAL loads column for all variables in equation	lb_m	See Table 4.129*
SXL	Standard Deviation, LOX Load (LO_2 Load @ T_o 1σ, NOR)	lb_m	See Table 8.4
SXH	Standard Deviation, LH_2 Load (LH_2 Load @ T_o 1σ, NOR)	lb_m	See Table 8.4
SXLNOP	No PLOAD Standard Deviation, LOX Load (LO_2 Load @ T_o 1σ, NOR)	lb_m	See Table 8.4
SXHNOP	No PLOAD Standard Deviation, LH_2 Load (LH_2 Load @ T_o 1σ, NOR)	lb_m	See Table 8.4
SXP	Standard Deviation, MR (OBMR 1σ, NOR)	n/a	See Table 8.4
SZL	Standard Deviation, LOX Vapor (GO_2 Pressurant 1σ, NOR)	lb_m	See Table 8.4
SZH	Standard Deviation, LH_2 Vapor (GH_2 Pressurant 1σ, NOR)	lb_m	See Table 8.4
GAM	Propellant Sensitivity, Expressed as Delta WP/Delta GLOW (Gamma, NOR)	n/a	See Table 8.4
SXC	Standard Deviation, 6:1 Effects (Sigma 6:1)	lb_m	See Table 4.128*
MUXC	Mean, 6:1 Effects (Mean 6:1)	lb_m	See Table 4.128*
DRATE	Drainback Rate DRATE = LO_2 Drainback lb_m/4.76667 min (4.76667 min = 4 min 55 sec minus 9 sec for Valve Closing)	lb_m/min	See Table 4.128*

TABLE 4.1.2

DAY-OF-LAUNCH MARGINS PROGRAM INPUTS (LWT) - (Concluded)

MARGINS VARIABLE NAME	DESCRIPTION (SPAD variable name)	UNITS	VALUE
LOXUNC	3-Sigma LOX Loading Uncertainty (LO_2 Load %)	lb_m	See Table 8.1
LH_2UNC	3-Sigma LH_2 Loading Uncertainty (LH_2 Load %)	lb_m	See Table 8.1
ULXNOP	No PLOAD 3-Sigma LOX Loading Uncertainty (LO_2 Load %)	lb_m	See Table 8.1
ULHNOP	No PLOAD 3-Sigma LH_2 Loading Uncertainty (LH_2 Load %)	lb_m	See Table 8.1

* NOTE: Values are also published in TDDP

TABLE 4.1.3

DAY-OF-LAUNCH MARGINS PROGRAM INPUTS (SLWT)

MARGINS VARIABLE NAME	DESCRIPTION (SPAD variable name)	UNITS	VALUE
MR	OBMR	n/a	See Table 4.135*
FBIAS	Nominal Fuel Bias (FUEL BIAS)	lb_m	See Table 4.135*
LOXLOD	Load at Engine Start Command, LO_2	lb_m	See Table 4.135*
LH_2LOD	Load at Engine Start Command, LH_2	lb_m	See Table 4.135*
WP	Usable Impulse, Used at OBMR, Total	lb_m	See Table 4.135*
UNMPS	Unusable Propellant for MARGINS UNMPS = <u>UNUSABLE</u> + Fuel Bias (BIAS) + VENTED AFTER SSME VALVE CLOSURE Note: Use TOTAL loads column for all variables in equation	lb_m	See Table 4.135*
SXL	Standard Deviation, LOX Load (LO_2 Load @ T_o 1σ, NOR)	lb_m	See Table 8.4
SXH	Standard Deviation, LH_2 Load (LH_2 Load @ T_o 1σ, NOR)	lb_m	See Table 8.4
SXLNOP	No PLOAD Standard Deviation, LOX Load (LO_2 Load @ T_o 1σ, NOR)	lb_m	See Table 8.4
SXHNOP	No PLOAD Standard Deviation, LH_2 Load (LH_2 Load @ T_o 1σ, NOR)	lb_m	See Table 8.4
SXP	Standard Deviation, MR (OBMR 1σ, NOR)	n/a	See Table 8.4
SZL	Standard Deviation, LOX Vapor (GO_2 Pressurant 1σ, NOR)	lb_m	See Table 8.4
SZH	Standard Deviation, LH_2 Vapor (GH_2 Pressurant 1σ, NOR)	lb_m	See Table 8.4
GAM	Propellant Sensitivity, Expressed as Delta WP/Delta GLOW (Gamma, NOR)	n/a	See Table 8.4
SXC	Standard Deviation, 6:1 Effects (Sigma 6:1)	lb_m	See Table 4.134*
MUXC	Mean, 6:1 Effects (Mean 6:1)	lb_m	See Table 4.134*
DRATE	Drainback Rate DRATE = LO_2 Drainback lb_m/4.76667 min (4.76667 min = 4 min 55 sec minus 9 sec for Valve Closing)	lb_m/min	See Table 4.134*

TABLE 4.1.3

DAY-OF-LAUNCH MARGINS PROGRAM INPUTS (SLWT) - (Concluded)

MARGINS VARIABLE NAME	DESCRIPTION (SPAD variable name)	UNITS	VALUE
LOXUNC	3-Sigma LOX Loading Uncertainty (LO_2 Load %)	lb_m	See Table 8.1
LH_2UNC	3-Sigma LH_2 Loading Uncertainty (LH_2 Load %)	lb_m	See Table 8.1
ULXNOP	No PLOAD 3-Sigma LOX Loading Uncertainty (LO_2 Load %)	lb_m	See Table 8.1
ULHNOP	No PLOAD 3-Sigma LH_2 Loading Uncertainty (LH_2 Load %)	lb_m	See Table 8.1

*NOTE: Values are also published in TDDP

TABLE 4.1.4

LWT TANKING TABLE DATA, LWT-68 AND SUBS

LO_2	Level Sensor	Tank X_T Location	Vol (ft^3) @ 0.00 psig	Vol (ft^3) @ 0.27 psig	Vol (ft^3) @ 0.76 psig	Vol (ft^3) @ 21.00 psig
	Overfill	399.69	19,551.79	19,552.44	19,553.63	19,601.99
	100% +	409.48	19,504.07	19,504.72	19,505.91	19,554.22
	100%	412.58	19,486.25	19,486.89	19,488.08	19,536.36
	100% –	415.48	19,468.32	19,468.97	19,470.16	19,518.41
	98%	455.00	19,093.64	19,094.29	19,095.46	19,142.72
LH_2	Level Sensor	Tank X_T Location	Vol (ft^3) @ 0.00 psig	Vol (ft^3) @ 0.15 psig	Vol (ft^3) @ 0.30 psig	Vol (ft^3) @ 27.75 psig
	Overfill	1,033.40	52,734.17	52,735.57	52,736.95	52,991.74
	100% +	1,040.60	52,609.29	52,610.68	52,612.06	52,865.88
	100%	1,044.60	52,525.94	52,527.33	52,528.71	52,781.91
	100% –	1,048.50	52,435.58	52,436.98	52,438.34	52,690.94
	98%	1,102.10	50,486.71	50,488.02	50,489.32	50,728.35

TABLE 4.1.5

SLWT TANKING TABLE DATA, SLWT-01 AND SUBS

LO_2	Level Sensor	Tank X_T Location	Vol (ft^3) @ 0.00 psig	Vol (ft^3) @ 0.30 psig	Vol (ft^3) @ 0.76 psig	Vol (ft^3) @ 22.00 psig
	Overfill	399.69	19,565.35	19,566.13	19,567.33	19,622.86
	100% +	409.48	19,519.16	19,519.93	19,521.11	19,575.44
	100%	412.58	19,501.87	19,502.63	19,503.80	19,557.72
	100% –	415.48	19,484.43	19,485.19	19,486.35	19,539.87
	98%	455.00	19,117.13	19,117.79	19,118.81	19,165.87
LH_2	Level Sensor	Tank X_T Location	Vol (ft^3) @ 0.00 psig	Vol (ft^3) @ 0.15 psig	Vol (ft^3) @ 0.30 psig	Vol (ft^3) @ 29.30 psig
	Overfill	1,033.40	52,749.35	52,751.09	52,752.84	53,090.40
	100% +	1,040.60	52,623.86	52,625.60	52,627.35	52,964.97
	100%	1,044.60	52,540.27	52,542.01	52,543.76	52,881.61
	100% –	1,048.50	52,449.72	52,451.46	52,453.21	52,790.94
	98%	1,102.10	50,500.38	50,502.09	50,503.80	50,834.26

TABLE 4.1.6

LO_2 ULLAGE PRESSURE REDUCTION EQUATIONS, CURVE FIT COEFFICIENTS

Equation	Constant	x Term	x^2 Term	x^3 Term	x^4 Term
coeff_nom	1.999360	– 2.0031373E-04	1.4885179E-08	– 5.8646843E-13	9.1265103E-18
coeff_max	2.696281	– 4.1096495E-04	4.5381444E-08	– 2.3830885E-12	4.5648571E-17
coeff_min	1.485296	– 5.1531559E-05	– 6.2601861E-09	6.2773414E-13	– 1.4962420E-17

TABLE 4.1.7

VENTED AND PRESSURIZED LH_2 PROPELLANT BULK CONDITIONS VERSUS GH_2 ULLAGE PRESSURE

Ullage Pressure (psia)	Vented (@ EOR)		Pressurized (@ ESC)	
	Bulk Density (lb_m/ft^3)	Bulk Temperature (°R)	Bulk Density (lb_m/ft^3)	Bulk Temperature (°R)
14.0	4.426672	36.33	4.435718	36.53
14.1	4.424995	36.37	4.434008	36.57
14.2	4.423323	36.41	4.432303	36.61
14.3	4.421655	36.45	4.430601	36.65
14.4	4.419991	36.49	4.428903	36.69
14.5	4.418332	36.54	4.427209	36.74
14.6	4.416676	36.58	4.425520	36.78
14.7	4.415025	36.62	4.423834	36.82
14.8	4.413379	36.66	4.422152	36.86
14.9	4.411736	36.70	4.420475	36.90
15.0	4.410098	36.74	4.418802	36.94
15.1	4.408465	36.78	4.417132	36.98
15.2	4.406836	36.82	4.415467	37.02
15.3	4.405211	36.86	4.413806	37.06
15.4	4.403591	36.91	4.412150	37.11
15.5	4.401975	36.95	4.410497	37.15
15.6	4.400364	36.99	4.408849	37.19
15.7	4.398757	37.02	4.407206	37.22
15.8	4.397155	37.06	4.405566	37.26
15.9	4.395558	37.10	4.403931	37.30
16.0	4.393965	37.14	4.402300	37.34
16.1	4.392377	37.18	4.400674	37.38
16.2	4.390794	37.22	4.399052	37.42
16.3	4.389215	37.26	4.397435	37.46
16.4	4.387641	37.30	4.395822	37.50
16.5	4.386072	37.34	4.394214	37.54
16.6	4.384508	37.38	4.392610	37.58
16.7	4.382949	37.41	4.391011	37.61
16.8	4.381394	37.45	4.389416	37.65
16.9	4.379844	37.49	4.387826	37.69
17.0	4.378300	37.53	4.386241	37.73
17.1	4.376760	37.56	4.384660	37.76
17.2	4.375225	37.60	4.383084	37.80
17.3	4.373695	37.64	4.381513	37.84
17.4	4.372170	37.68	4.379947	37.88
17.5	4.370651	37.71	4.378385	37.91
17.6	4.369136	37.75	4.376828	37.95

TABLE 4.1.8

VENTED AND PRESSURIZED LO_2 PROPELLANT BULK CONDITIONS VERSUS GO_2 ULLAGE PRESSURE

Ullage Pressure (psia)	Vented (@ EOR)		Pressurized (@ ESC)	
	Bulk Density (lb_m/ft^3)	Bulk Temperature (°R)	Bulk Density (lb_m/ft^3)	Bulk Temperature (°R)
14.6	71.309962	161.95	71.317975	162.02
14.7	71.287595	162.08	71.295541	162.15
14.8	71.265298	162.21	71.273176	162.28
14.9	71.243071	162.34	71.250881	162.41
15.0	71.220915	162.47	71.228656	162.54
15.1	71.198829	162.59	71.206501	162.66
15.2	71.176813	162.72	71.184415	162.79
15.3	71.154867	162.85	71.162400	162.92
15.4	71.132992	162.98	71.140456	163.05
15.5	71.111188	163.10	71.118581	163.17
15.6	71.089455	163.23	71.096777	163.30
15.7	71.067792	163.35	71.075044	163.42
15.8	71.046201	163.48	71.053381	163.55
15.9	71.024680	163.60	71.031789	163.67
16.0	71.003231	163.73	71.010268	163.80
16.1	70.981853	163.85	70.988818	163.92
16.2	70.960547	163.97	70.967439	164.04
16.3	70.939312	164.09	70.946131	164.16
16.4	70.918149	164.22	70.924895	164.29
16.5	70.897057	164.34	70.903730	164.41
16.6	70.876037	164.46	70.882636	164.53
16.7	70.855090	164.58	70.861614	164.65
16.8	70.834214	164.70	70.840663	164.77
16.9	70.813410	164.82	70.819784	164.89
17.0	70.792678	164.94	70.798978	165.01
17.1	70.772019	165.06	70.778243	165.13
17.2	70.751432	165.17	70.757580	165.24
17.3	70.730918	165.29	70.736989	165.36
17.4	70.710476	165.41	70.716471	165.48
17.5	70.690107	165.53	70.696025	165.60
17.6	70.669811	165.64	70.675651	165.71

TABLE 4.1.9

PLOAD PROGRAM INPUTS, LWT AND SLWT

Input Name	Data Type	Description (Units)	Value
lox_volume_coeff	float (array size 2)	Volume of LO_2 tank occupied by LO_2 at the 100% #1 sensor (ft^3) lox_volume_coeff (b and m) are the constants in the point slope equation y = mx + b. Solve for the coefficients by constructing 2 equations, using data from the 2 columns bracketing the operational pressure range. Let x1 = the psig of the lower bound and x2 = the psig of the upper bound Let y1 = the LO_2 100% level sensor volume for x1 Let y2 = the LO_2 100% level sensor volume for x2	LWT - Table 4.1.4 SLWT - Table 4.1.5
lh2_volume_coeff	float (array size 2)	Volume of LH_2 tank occupied by LH_2 at the 100% #1 sensor (ft^3) lh2_volume_coeff (b and m) are the constants in the point slope equation y = mx + b. Solve for the coefficients by constructing 2 equations, using data from the 2 columns bracketing the operational pressure range. Let x1 = the psig of the lower bound and x2 = the psig of the upper bound Let y1 = the LO_2 100% level sensor volume for x1 Let y2 = the LO_2 100% level sensor volume for x2	LWT - Table 4.1.4 SLWT - Table 4.1.5

TABLE 4.1.9

PLOAD PROGRAM INPUTS, LWT AND SLWT - Continued

Input Name	Data Type	Description (Units)	Value
lox_bubble_volume	float	Volume of helium bubble in LO_2 tank (ft^3)	LWT - Table 4.128 SLWT - Table 4.134
lh2_bubble_volume	float	Volume of helium bubble in LH_2 tank (ft^3)	LWT - Table 4.128 SLWT - Table 4.134
nose_cap_pressure	float	Nose cap positive pressure due to purge gas flow (psid)	LWT - Table 4.128 SLWT - Table 4.134
lox_drain	float	Nominal amount of LO_2 lost due to drainback, etc. from EOR to ESC (lb_m)	LWT - Table 4.128 SLWT - Table 4.134
lh2_drain	float	Nominal amount of LH_2 lost due to boil off, etc. from EOR to ESC (lb_m)	LWT - Table 4.129 SLWT - Table 4.135
lox_mass_in_lines	float	LO_2 mass in Orbiter (lb_m) lox_mass_in_lines = LO_2 in ORB LINES + LO_2 in SSME x 3 Note: Use Load at Engine Start Command for both variables	LWT - Table 4.129 SLWT - Table 4.135
lh2_mass_in_lines	float	LH_2 mass in Orbiter (lb_m) lh2_mass_in_lines = LH_2 in ORB LINES + LH_2 in SSME x 3 Note: Use Load at Engine Start Command for both variables	LWT - Table 4.129 SLWT - Table 4.135
lox_reference_load	float	LO_2 TDDP load at Engine Start Command (lb_m)	LWT - Table 4.129 SLWT - Table 4.135

TABLE 4.1.9

PLOAD PROGRAM INPUTS, LWT AND SLWT - (Concluded)

Input Name	Data Type	Description (Units)	Value
lh2_reference_load	float	LH_2 TDDP load at Engine Start Command (lb_m)	LWT - Table 4.129 SLWT - Table 4.135
coeff_nom	float (array size 5)	Polynomial coefficients for nominal LO_2 ullage pressure decay	All Inv - Table 4.1.6
coeff_max	float (array size 5)	Polynomial coefficients for maximum LO_2 ullage pressure decay	All Inv - Table 4.1.6
coeff_min	float (array size 5)	Polynomial coefficients for minimum LO_2 ullage pressure decay	All Inv - Table 4.1.6
ullage_pressure	float (array size 50)	Ullage pressure for LO_2 or LH_2 (psia)	All Inv - Table 4.1.7 and Table 4.1.8
bulk_density	float (array size 50)	Bulk density for LO_2 or LH_2 (lb_m/ft^3)	All Inv - Table 4.1.7 and Table 4.1.8

TABLE 4.1.10

ORBITER MPS PROPELLANT DUMP PERFORMANCE SUMMARY (NO-FAIL TRAJECTORY)

Parameter	Propellant Mass, lb_m	
	LO_2	LH_2
Propellant mass at MECO	4802[a]	365
Propellant loss from MECO to ET separation		
Vented after SSME Valve Closure	172	58
Helium POGO injection (10 ft^3)	710[b]	N/A
Disconnect closure (0.7 ft^3)	50	3
Propellant mass at ET separation	3870	304
Propellant loss from ET separation to start of dump		
HPOTP seal leakage (120 seconds)	270	N/A
LH_2 feedline venting (110 seconds)	N/A	157
Propellant mass at start of dump	3600	147
Propellant mass dumped	3400	143
Propellant mass at end of dump	<200	<4
Mass dumped during fill/drain line vacuum inerting	<200	<4
Propellant mass at touchdown	0	0

[a] The LO_2 propellant mass at MECO, for LLCO, is 4,052 lb_m (three SSMEs at 67% RPL) instead of the 4,802 lb_m for guided MECO.

[b] Helium POGO injection displaces LO_2 into ET during SSME shutdown.

TABLE 4.1.11

ORBITER MPS PROPELLANT DUMP PERFORMANCE SUMMARY (AOA/ATO TRAJECTORY, ONE ENGINE OUT)

Parameter	Propellant Mass, lb_m	
	LO_2	LH_2
Propellant mass at MECO	4508[a]	346
Propellant loss from MECO to ET separation		
Vented after SSME Valve Closure	115	39
Helium POGO injection (6.67 ft^3)	473[b]	N/A
Disconnect closure (0.7 ft^3)	50	3
Propellant mass at ET separation	3870	304
Propellant loss from ET separation to start of dump		
HPOTP seal leakage (120 seconds)	270	N/A
LH_2 feedline venting (110 seconds)	N/A	157
Propellant mass at start of dump	3600	147
Propellant mass dumped	3400	143
Propellant mass at end of dump	<200	<4
Mass dumped during fill/drain line vacuum inerting	<200	<4
Propellant mass at touchdown	0	0

[a] The LO_2 propellant mass at MECO, for LLCO, is 4,188 lb_m (two SSMEs at 91% RPL) instead of the 4,508 lb_m for guided MECO.

[b] Helium POGO injection displaces LO_2 into ET during two SSMEs shutdown.

TABLE 4.1.12

ORBITER MPS PROPELLANT DUMP PERFORMANCE SUMMARY (TAL TRAJECTORY, ONE ENGINE OUT)

Parameter	Propellant Mass, lb_m	
	LO_2	LH_2
Propellant mass at MECO	4508[a]	346
Propellant loss from MECO to ET separation		
Vented after SSME Valve Closure	115	39
Helium POGO injection (6.67 ft^3)	473[b]	N/A
Disconnect closure (0.7 ft^3)	50	3
Propellant mass at ET separation	3870	304
Propellant loss from ET separation to start of dump		
HPOTP seal leakage (0 seconds)	0	N/A
LH_2 feedline venting (30 seconds)	N/A	51
Propellant mass at start of dump	3870	253
Propellant mass dumped	3870	253
Propellant mass at end of dump	<1	<1
Mass dumped during fill/drain line vacuum inerting	<1	<1
Propellant mass at touchdown	0	0

[a] The LO_2 propellant mass at MECO, for LLCO, is 4,188 lb_m (two SSMEs at 91% RPL) instead of the 4,508 lb_m for guided MECO.

[b] Helium POGO injection displaces LO_2 into ET during two SSMEs shutdown.

TABLE 4.1.13

ORBITER MPS PROPELLANT DUMP PERFORMANCE SUMMARY (RTLS TRAJECTORY, ONE ENGINE OUT)

Parameter	Propellant Mass, lb_m	
	LO_2	LH_2
Propellant mass at MECO	4508[a]	346
Propellant loss from MECO to ET separation		
Vented after SSME Valve Closure	115	39
Helium POGO injection (6.67 ft^3)	473[b]	N/A
Disconnect closure (0.7 ft^3)	50	3
Propellant mass at ET separation	3870	304
Propellant loss from ET separation to start of dump		
HPOTP seal leakage	0	N/A
LH_2 feedline venting (15 seconds)	N/A	28
Propellant mass at start of dump	3870	276
Propellant mass dumped	3870	275
Propellant mass at end of dump	<1	<2
Mass dumped during fill/drain line vacuum inerting	<1	<2
Propellant mass at touchdown	0	0

[a] The LO_2 propellant mass at MECO, for LLCO, is 4,250 lb_m (two SSMEs at 67% RPL) instead of the 4,508 lb_m for guided MECO.

[b] Helium POGO injection displaces LO_2 into ET during two SSMEs shutdown.

TABLES 4.2 THRU 4.127 – (RELOCATED TO NEW APPENDIX G)

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TABLE 4.128

STS-GEN R0103L MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)

ITEM		LO_2	LH_2
Vented Ullage Pressure (psig)	=	0.79	0.20
Unusable: LO_2 Line, LH_2 Tank + Line (lb_m)	=	511.2	720.0
Unpressurized Density (lb_m/ft^3)	=	71.129717	4.412557
Pressurized Density (lb_m/ft^3)	=	71.137170	4.421313
Sensor Station (X_T)	=	412.58	1044.60
Percent Ullage Volume at ESC (%)	=	1.573717	1.720268
Bubble Volume (ft^3)	=	40.00	162.50
Total Tank Vol (Pressurized) (ft^3)	=	19671.92	53152.43
Tank Volume Below Sensor (Vented) (ft^3)	=	19488.14	52527.79

LO_2 Drainback (lb_m)	=	5958.7	Fuel Bias (lb_m)	=	1112
LO_2 ECO Timer (sec)	=	0.3580	Min LO_2 NPSP (psi)	=	6.1000
Range	=	ETR	System MR (MRU)	=	6.0414
Atmos Press (psia)	=	14.75	Nosecap Del P (psid)	=	0.01
LH_2 Alt Corr (psid)	=	−0.1	LO_2 Alt Corr (psid)	=	−0.13
Mean 6:1	=	69.0	Sigma 6:1	=	843.0
Mean Non 6:1	=	12.30	Sigma Non 6:1	=	516.47
Sigma Level	=	3.00	Mean +3-Sigma FPR	=	3046.77

TABLE 4.129

STS-GEN R0103L MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)

Fuel Bias = 1112.	Throttle Setting NOM/AOA = 104.5/104.5	SYSTEM MR = 6.0414		
Total FPR = 3047.	% ULL O_2 = 1.57 SIGMA = 3.000	OBMR = 6.0550		
CNTRL MR = 6.03200	% ULL H_2 = 1.72	LH_2	LO_2	TOTAL
Loaded		231372.	1387970.	1619342.
ORB Lines		249.	3304.	3553.
SSME × 3		58.	1325.	1383.
ET (HXT = 1044.6 HUP = .20 LXT = 412.58 LUP = 0.785)		231065.	1383341.	1614406.
Loss Prior to Eng Start CMD DBT 4.M:55.S		104.	5959.	6063.
Boil off, Drainback, etc.		104.	5959.	6063.
Load at Engine Start Command		231268.	1382011.	1613279.
ORB Lines		249.	3304.	3553.
SSME × 3		58.	1325.	1383.
ET		230961.	1377382.	1608343.
Transferred from ET to SSME × 3		58.	172.	230.
Loss for THR Buildup and SRB IGN Delay		1796.	9534.	11330.
Load at SRB Ignition Command		229472.	1372477.	1601949.
ORB Lines		249.	3304.	3553.
SSME × 3		116.	1497.	1613.
ET		229107.	1367676.	1596783.
Unusable		2000.	4814.	6814.
ORB Lines (LO_2 ECO T = 0.358 NPSP = 6.1)		249.	511.	760.
SSME × 3		58.	1325.	1383.
ET Wet Walls, Bellows		0.	175.	175.
ET: LH_2 Lines and Tank; LO_2 Lines		720.	0.	720.
Flight Press		974.	2803.	3776.
Usable Reserves		1544.	2615.	4158.
ORB Lines (FPR)		0.	2615.	2615.
SSME × 3		0.	0.	0.
ET (FPR)		432.	0.	432.
Bias		1112.	0.	1112.
Usable Impulse		225928.	1365048.	1590976.
Used at OBMR		225180.	1363474.	1588655.
Shutdown Consumption		690.	1402.	2092.
0 SSMEs from NOM PCT Throttle Setting		0.	0.	0.
3 SSMEs from 67 PCT Throttle Setting		690.	1402.	2092.
Vented after SSME Valve Closure		58.	172.	230.

TABLE 4.130

STS-GEN R0103L MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)

ITEM		LO_2	LH_2
Vented Ullage Pressure (psig)	=	0.79	0.20
Unusable: LO_2 Line, LH_2 Tank + Line (lb_m)	=	1441.4	810.0
Unpress Density (lb_m/ft^3)	=	71.129717	4.412557
Press Density (lb_m/ft^3)	=	71.137170	4.421313
Sensor Station (X_T)	=	412.58	1044.60
Percent Ullage Vol at ESC (%)	=	1.573717	1.720268
Bubble Vol (ft^3)	=	40.00	162.50
Total Tank Vol (Pressurized) (ft^3)	=	19671.92	53152.43
Tank Vol Below Sensor (Vented) (ft^3)	=	19488.14	52527.79

LO_2 Drainback (lb_m)	=	5958.7	Fuel Bias (lb_m)	=	1069
LO_2 ECO Timer (sec)	=	0.0000	Min LO_2 NPSP (psi)	=	7.7000
Range	=	ETR	System MR (MRU)	=	6.0414
Atmos Press (psia)	=	14.75	Nosecap Del P (psid)	=	0.01
LH_2 Alt Corr (psid)	=	−0.1	LO_2 Alt Corr (psid)	=	−0.13
Mean 6:1	=	208.0	Sigma 6:1	=	865.0
Mean Non 6:1	=	22.09	Sigma Non 6:1	=	495.00
Sigma Level	=	2.00	Mean +2-Sigma FPR	=	2224.70

TABLE 4.131

STS-GEN R0103L MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)

Fuel Bias = 1069.	Throttle Setting NOM/AOA = 104.5/104.5	SYSTEM MR = 6.0414		
Total FPR = 2225.	% ULL O_2 = 1.57 SIGMA = 2.000	OBMR = 6.0565		
CNTRL MR = 6.03200	% ULL H_2 = 1.72	LH_2	LO_2	TOTAL
Loaded		231372.	1387970.	1619342.
ORB Lines		249.	3304.	3553.
SSME × 3		58.	1325.	1383.
ET (HXT = 1044.6 HUP = .20 LXT = 412.58 LUP = 0.785)		231065.	1383341.	1614406.
Loss Prior to Eng Start CMD DBT 4.M:55.S		104.	5959.	6063.
Boil off, Drainback, etc.		104.	5959.	6063.
Load at Engine Start Command		231268.	1382011.	1613279.
ORB Lines		249.	3304.	3553.
SSME × 3		58.	1325.	1383.
ET		230961.	1377382.	1608343.
Transferred from ET to SSME × 3		58.	172.	230.
Loss for THR Buildup and SRB IGN Delay		1796.	9534.	11330.
Load at SRB Ignition Command		229472.	1372477.	1601949.
ORB Lines		249.	3304.	3553.
SSME × 3		116.	1497.	1613.
ET		229107.	1367676.	1596783.
Unusable		2159.	5829.	7988.
ORB Lines (LO_2 ECO T = 0.000 NPSP = 7.7)		249.	1441.	1690.
SSME × 3		58.	1325.	1383.
ET Wet Walls, Bellows		0.	175.	175.
ET: LH_2 Lines and Tank; LO_2 Lines		810.	0.	810.
Flight Press		1042.	2887.	3930.
Usable Reserves		1384.	1909.	3294.
ORB Lines (FPR)		0.	1863.	1863.
SSME × 3		0.	0.	0.
ET (FPR)		315.	47.	362.
Bias		1069.	0.	1069.
Usable Impulse		225928.	1364739.	1590667.
Used at OBMR		224948.	1362401.	1587349.
Shutdown Consumption		922.	2165.	3088.
1 SSME from NOM PCT Throttle Setting		332.	802.	1134.
2 SSMEs from 91 PCT Throttle Setting		590.	1363.	1954.
Vented after SSME Valve Closure		58.	172.	230.

TABLE 4.132

STS-GEN R0103L MPS PROPELLANT INVENTORY INPUT SHEET (RTLS)

ITEM		LO_2	LH_2
Vented Ullage Pressure (psig)	=	0.79	0.20
Unusable: LO_2 Line, LH_2 Tank + Line (lb_m)	=	2219.5	920.0
Unpress Density (lb_m/ft^3)	=	71.129717	4.412557
Press Density (lb_m/ft^3)	=	71.137170	4.421313
Sensor Station (X_T)	=	412.58	1044.60
Percent Ullage Vol at ESC (%)	=	1.573717	1.720268
Bubble Vol (ft^3)	=	40.00	162.50
Total Tank Vol (Pressurized) (ft^3)	=	19671.92	53152.43
Tank Vol Below Sensor (Vented) (ft^3)	=	19488.14	52527.79

LO_2 Drainback (lb_m)	=	5958.7	Fuel Bias (lb_m)	=	1148
LO_2 ECO Timer (sec)	=	0.0000	Min LO_2 NPSP (psi)	=	7.5000
Range	=	ETR	System MR (MRU)	=	6.0414
Atmos Press (psia)	=	14.75	Nosecap Del P (psid)	=	0.01
LH_2 Alt Corr (psid)	=	−0.1	LO_2 Alt Corr (psid)	=	−0.13
Mean 6:1	=	138.0	Sigma 6:1	=	862.0
Mean Non 6:1	=	13.21	Sigma Non 6:1	=	488.00
Sigma Level	=	3.00	Mean +3-Sigma FPR	=	3124.17

TABLE 4.133

STS-GEN R0103L MPS PROPELLANT INVENTORY LOAD SHEET (RTLS)

Fuel Bias = 1148.	Throttle Setting NOM/AOA = 104.5/104.5	SYSTEM MR = 6.0414		
Total FPR = 3124.	% ULL O_2 = 1.57 SIGMA = 3.000	OBMR = 6.0559		
CNTRL MR = 6.03200	% ULL H_2 = 1.72	LH_2	LO_2	TOTAL
Loaded		231372.	1387970.	1619342.
ORB Lines		249.	3304.	3553.
SSME × 3		58.	1325.	1383.
ET (HXT = 1044.6 HUP = .20 LXT = 412.58 LUP = 0.785)		231065.	1383341.	1614406.
Loss Prior to Eng Start CMD DBT 4.M:55.S		104.	5959.	6063.
Boil off, Drainback, etc.		104.	5959.	6063.
Load at Engine Start Command		231268.	1382011.	1613279.
ORB Lines		249.	3304.	3553.
SSME × 3		58.	1325.	1383.
ET		230961.	1377382.	1608343.
Transferred from ET to SSME × 3		58.	172.	230.
Loss for THR Buildup and SRB IGN Delay		1796.	9534.	11330.
Load at SRB Ignition Command		229472.	1372477.	1601949.
ORB Lines		249.	3304.	3553.
SSME × 3		116.	1497.	1613.
ET		229107.	1367676.	1596783.
Unusable		2235.	6530.	8765.
ORB Lines (LO_2 ECO T = 0.000 NPSP = 7.5)		249.	2220.	2469.
SSME × 3		58.	1325.	1383.
ET Wet Walls, Bellows		0.	175.	175.
ET: LH_2 Lines and Tank; LO_2 Lines		920.	0.	920.
Flight Press		1008.	2811.	3819.
Usable Reserves		1591.	2681.	4272.
ORB Lines (FPR)		0.	1084.	1084.
SSME × 3		0.	0.	0.
ET (FPR)		443.	1597.	2040.
Bias		1148.	0.	1148.
Usable Impulse		225647.	1363265.	1588912.
Used at OBMR		224797.	1361356.	1586153.
Shutdown Consumption		792.	1737.	2529.
1 SSME from NOM PCT Throttle Setting		332.	802.	1134.
2 SSMEs from 67 PCT Throttle Setting		460.	935.	1394.
Vented after SSME Valve Closure		58.	172.	230.

TABLE 4.134

STS-GEN R0104S MPS PROPELLANT INVENTORY INPUT SHEET (NO FAIL)

ITEM		LO_2	LH_2
Vented Ullage Pressure (psig)	=	0.78	0.27
Unusable: LO_2 Line, LH_2 Tank + Line (lb_m)	=	511.2	720.0
Unpress Density (lb_m/ft^3)	=	71.130590	4.411490
Press Density (lb_m/ft^3)	=	71.138046	4.420224
Sensor Station (X_T)	=	412.58	1044.60
Percent Ullage Vol at ESC (%)	=	1.515790	1.831350
Bubble Vol (ft^3)	=	40.00	162.50
Total Tank Vol (Pressurized) (ft^3)	=	19676.30	53228.64
Tank Vol Below Sensor (Vented) (ft^3)	=	19503.85	52543.35

LO_2 Drainback (lb_m)	=	5958.7	Fuel Bias (lb_m)	=	937
LO_2 ECO Timer (sec)	=	0.3580	Min LO_2 NPSP (psi)	=	6.1000
Range	=	ETR	System MR (MRU)	=	6.0414
Atmos Press (psia)	=	14.75	Nosecap Del P (psid)	=	0.01
LH_2 Alt Corr (psid)	=	−0.1	LO_2 Alt Corr (psid)	=	−0.13
Mean 6:1	=	69.0	Sigma 6:1	=	843.0
Mean Non 6:1	=	33.67	Sigma Non 6:1	=	514.53
Sigma Level	=	3.00	Mean +3-Sigma FPR	=	3065.20

TABLE 4.135

STS-GEN R0104S MPS PROPELLANT INVENTORY LOAD SHEET (NO FAIL)

Fuel Bias = 937.	Throttle Setting NOM/AOA = 104.5/104.5	SYSTEM MR = 6.0414		
Total FPR = 3065.	% ULL O_2 = 1.52 SIGMA = 3.000	OBMR = 6.0550		
CNTRL MR = 6.03200	% ULL H_2 = 1.83	LH_2	LO_2	TOTAL
Loaded		231385.	1389104.	1620489.
ORB Lines		249.	3304.	3553.
SSME × 3		58.	1325.	1383.
ET (HXT = 1044.6 HUP = .265 LXT = 412.58 LUP = 0.781)		231078.	1384475.	1615553.
Loss Prior to Eng Start CMD DBT 4.M:55.S		104.	5959.	6063.
Boil off, Drainback, etc.		104.	5959.	6063.
Load at Engine Start Command		231281.	1383146.	1614426.
ORB Lines		249.	3304.	3553.
SSME × 3		58.	1325.	1383.
ET		230974.	1378517.	1609490.
Transferred from ET to SSME × 3		58.	172.	230.
Loss for THR Buildup and SRB IGN Delay		1796.	9534.	11330.
Load at SRB Ignition Command		229485.	1373611.	1603096.
ORB Lines		249.	3304.	3553.
SSME × 3		116.	1497.	1613.
ET		229120.	1368810.	1597930.
Unusable		2000.	4814.	6814.
ORB Lines (LO_2 ECO T = 0.358 NPSP = 6.1)		249.	511.	760.
SSME × 3		58.	1325.	1383.
ET Wet Walls, Bellows		0.	175.	175.
ET: LH_2 Lines and Tank; LO_2 Lines		720.	0.	720.
Flight Press		974.	2803.	3776.
Usable Reserves		1371.	2631.	4002.
ORB Lines (FPR)		0.	2631.	2631.
SSME × 3		0.	0.	0.
ET (FPR)		434.	0.	434.
Bias		937.	0.	937.
Usable Impulse		226113.	1366167.	1592280.
Used at OBMR		225365.	1364593.	1589959.
Shutdown Consumption		690.	1402.	2092.
0 SSMEs from NOM PCT Throttle Setting		0.	0.	0.
3 SSMEs from 67 PCT Throttle Setting		690.	1402.	2092.
Vented after SSME Valve Closure		58.	172.	230.

TABLE 4.136

STS-GEN R0104S MPS PROPELLANT INVENTORY INPUT SHEET (AOA/TAL)

ITEM		LO_2	LH_2
Vented Ullage Pressure (psig)	=	0.78	0.27
Unusable: LO_2 Line, LH_2 Tank + Line (lb_m)	=	1441.4	810.0
Unpress Density (lb_m/ft^3)	=	71.130590	4.411490
Press Density (lb_m/ft^3)	=	71.138046	4.420224
Sensor Station (X_T)	=	412.58	1044.60
Percent Ullage Vol at ESC (%)	=	1.515790	1.831350
Bubble Vol (ft^3)	=	40.00	162.50
Total Tank Vol (Pressurized) (ft^3)	=	19676.30	53228.64
Tank Vol Below Sensor (Vented) (ft^3)	=	19503.85	52543.35

LO_2 Drainback (lb_m)	=	5958.7	Fuel Bias (lb_m)	=	894
LO_2 ECO Timer (sec)	=	0.0000	Min LO_2 NPSP (psi)	=	7.7000
Range	=	ETR	System MR (MRU)	=	6.0414
Atmos Press (psia)	=	14.75	Nosecap Del P (psid)	=	0.01
LH_2 Alt Corr (psid)	=	−0.1	LO_2 Alt Corr (psid)	=	−0.13
Mean 6:1	=	208.0	Sigma 6:1	=	865.0
Mean Non 6:1	=	54.75	Sigma Non 6:1	=	507.05
Sigma Level	=	2.00	Mean +2-Sigma FPR	=	2268.80

TABLE 4.137

STS-GEN R0104S MPS PROPELLANT INVENTORY LOAD SHEET (AOA/TAL)

Fuel Bias = 894.	Throttle Setting NOM/AOA = 104.5/104.5	SYSTEM MR = 6.0414		
Total FPR = 2269.	% ULL O_2 = 1.52 SIGMA = 2.000	OBMR = 6.0565		
CNTRL MR = 6.03200	% ULL H_2 = 1.83	LH_2	LO_2	TOTAL
Loaded		231385.	1389104.	1620489.
ORB Lines		249.	3304.	3553.
SSME × 3		58.	1325.	1383.
ET (HXT = 1044.6 HUP = .265 LXT = 412.58 LUP = 0.781)		231078.	1384475.	1615553.
Loss Prior to Eng Start CMD DBT 4.M:55.S		104.	5959.	6063.
Boil off, Drainback, etc.		104.	5959.	6063.
Load at Engine Start Command		231281.	1383146.	1614426.
ORB Lines		249.	3304.	3553.
SSME × 3		58.	1325.	1383.
ET		230974.	1378517.	1609490.
Transferred from ET to SSME × 3		58.	172.	230.
Loss for THR Buildup and SRB IGN Delay		1796.	9534.	11330.
Load at SRB Ignition Command		229485.	1373611.	1603096.
ORB Lines		249.	3304.	3553.
SSME × 3		116.	1497.	1613.
ET		229120.	1368810.	1597930.
Unusable		2159.	5829.	7988.
ORB Lines (LO_2 ECO T = 0.000 NPSP = 7.7)		249.	1441.	1690.
SSME × 3		58.	1325.	1383.
ET Wet Walls, Bellows		0.	175.	175.
ET: LH_2 Lines and Tank; LO_2 Lines		810.	0.	810.
Flight Press		1042.	2887.	3930.
Usable Reserves		1216.	1947.	3163.
ORB Lines (FPR)		0.	1863.	1863.
SSME × 3		0.	0.	0.
ET (FPR)		322.	85.	406.
Bias		894.	0.	894.
Usable Impulse		226110.	1365835.	1591945.
Used at OBMR		225129.	1363498.	1588627.
Shutdown Consumption		922.	2165.	3088.
1 SSME from NOM PCT Throttle Setting		332.	802.	1134.
2 SSMEs from 91 PCT Throttle Setting		590.	1363.	1954.
Vented after SSME Valve Closure		58.	172.	230.

TABLE 4.138

STS-GEN R0104S MPS PROPELLANT INVENTORY INPUT SHEET (RTLS)

ITEM		LO_2	LH_2
Vented Ullage Pressure (psig)	=	0.78	0.27
Unusable: LO_2 Line, LH_2 Tank + Line (lb_m)	=	2219.5	920.0
Unpress Density (lb_m/ft^3)	=	71.130590	4.411490
Press Density (lb_m/ft^3)	=	71.138046	4.420224
Sensor Station (X_T)	=	412.58	1044.60
Percent Ullage Vol at ESC (%)	=	1.515790	1.831350
Bubble Vol (ft^3)	=	40.00	162.50
Total Tank Vol (Pressurized) (ft^3)	=	19676.30	53228.64
Tank Vol Below Sensor (Vented) (ft^3)	=	19503.85	52543.35

LO_2 Drainback (lb_m)	=	5958.7	Fuel Bias (lb_m)	=	973
LO_2 ECO Timer (sec)	=	0.0000	Min LO_2 NPSP (psi)	=	7.5000
Range	=	ETR	System MR (MRU)	=	6.0414
Atmos Press (psia)	=	14.75	Nosecap Del P (psid)	=	0.01
LH_2 Alt Corr (psid)	=	−0.1	LO_2 Alt Corr (psid)	=	−0.13
Mean 6:1	=	138.0	Sigma 6:1	=	862.0
Mean Non 6:1	=	35.88	Sigma Non 6:1	=	491.63
Sigma Level	=	3.00	Mean +3-Sigma FPR	=	3150.59

TABLE 4.139

STS-GEN R0104S MPS PROPELLANT INVENTORY LOAD SHEET (RTLS)

Fuel Bias = 973.	Throttle Setting NOM/AOA = 104.5/104.5	SYSTEM MR = 6.0414		
Total FPR = 3151.	% ULL O_2 = 1.52 SIGMA = 3.000	OBMR = 6.0559		
CNTRL MR = 6.03200	% ULL H_2 = 1.83	LH_2	LO_2	TOTAL
Loaded		231385.	1389104.	1620489.
ORB Lines		249.	3304.	3553.
SSME × 3		58.	1325.	1383.
ET (HXT = 1044.6 HUP = .265 LXT = 412.58 LUP = 0.781)		231078.	1384475.	1615553.
Loss Prior to Eng Start CMD DBT 4.M:55.S		104.	5959.	6063.
Boil off, Drainback, etc.		104.	5959.	6063.
Load at Engine Start Command		231281.	1383146.	1614426.
ORB Lines		249.	3304.	3553.
SSME × 3		58.	1325.	1383.
ET		230974.	1378517.	1609490.
Transferred from ET to SSME × 3		58.	172.	230.
Loss for THR Buildup and SRB IGN Delay		1796.	9534.	11330.
Load at SRB Ignition Command		229485.	1373611.	1603096.
ORB Lines		249.	3304.	3553.
SSME × 3		116.	1497.	1613.
ET		229120.	1368810.	1597930.
Unusable		2235.	6530.	8765.
ORB Lines (LO_2 ECO T = 0.000 NPSP = 7.5)		249.	2220.	2468.
SSME × 3		58.	1325.	1383.
ET Wet Walls, Bellows		0.	175.	175.
ET: LH_2 Lines and Tank; LO_2 Lines		920.	0.	920.
Flight Press		1008.	2811.	3819.
Usable Reserves		1419.	2704.	4123.
ORB Lines (FPR)		0.	1084.	1084.
SSME × 3		0.	0.	0.
ET (FPR)		447.	1620.	2066.
Bias		973.	0.	973.
Usable Impulse		225831.	1364377.	1590208.
Used at OBMR		224981.	1362468.	1587449.
Shutdown Consumption		792.	1737.	2529.
1 SSME from NOM PCT Throttle Setting		332.	802.	1134.
2 SSMEs from 67 PCT Throttle Setting		460.	935.	1394.
Vented after SSME Valve Closure		58.	172.	230.

5.0 PROPULSION PERFORMANCE

Propulsion performance characteristics for the Space Shuttle are established in this section. The propulsion systems consist of the MPS, OMS, RCS and RSRM.

5.1 MAIN PROPULSION SYSTEM

The Space Shuttle MPS is shown in Figure 5-1 and consists of the SSMEs, ET, propellant feed management, fill and drain, conditioning, pressurization control, pneumatic supply, SSME GN_2 purge, helium, engine heat shield, and POGO suppression. The usable ascent propellants for SSME operation are provided from the ET. The ET is separated from the Orbiter after MECO and prior to achieving orbit. The ET breaks up and scatters in the ocean after separation and is not reusable. Five MPS fluid lines interface with the ET through disconnects located at the bottom of the Orbiter aft fuselage. Three hydrogen disconnects are mounted on a carrier plate on the port side of the Orbiter and two oxygen disconnects are mounted on the starboard side. Ground servicing of the MPS is provided through umbilicals on each side of the aft fuselage.

A schematic of the MPS (excluding the pneumatic supply and GN_2 purge) is shown in Figure 5-2. The propellant feed lines supply propellants (LH_2 and LO_2) to the SSMEs from the ET. The propellant fill and drain lines provide propellants to the ET during loading and propellant drain-back capability while on the ground. The propellant conditioning system provides conditioned propellants to the SSMEs for engine start. The pressurization control system maintains the proper pressures in the ET. The pump inlet pressure required for the startup transient is provided by the propellant hydrostatic head plus pressurization with ground - supplied Gaseous Helium (GHe). Following engine thrust build-up, tank pressure is maintained with vaporized propellants extracted from the SSMEs. The ET ullage pressures during boost are maintained to meet Net Positive Suction Pressure (NPSP) requirements of the SSMEs. Pneumatics are supplied by a 4500-psia helium storage system with 750-psig regulation for valve actuation, SSME purge, and backup SSME shutdown. Expulsion of residual propellants after MECO and repressurization of MPS lines for reentry are provided by a 20-psig helium regulated supply. A GN_2 purge is used to inert the SSMEs prior to startup. The propellant feed management system controls propellant loading and provides Low-level Cutoff (LLCO) information which is a backup to the normal velocity cutoff function. LH_2 LLCO sensors are located at XT 2143.2 in the LH_2 tank and LO_2 ECO sensors are located at XT 1330.5 in the LO_2 manifold.

Each of the three SSMEs, illustrated in Figure 5-3, at RPL, is capable of producing a thrust of 375,000 pounds at sea level and 470,000 pounds in a vacuum. The LO_2 and LH_2 propellants are supplied to each SSME at a nominal inlet flowrate of 886 lb_m/sec and 148 lb_m/sec, respectively.

The calculation of the optimum assessment MR must consider, in addition to the fuel bias, the following MPS parameters:

a. Propellant consumed in buildup and shutdown

b. Propellant trapped

c. Propellant used to pressurize ET

d. Propellant vented subsequent to MECO command

The assessment MR is converted to SSME suction MR (defined at standard pressurant supply flowrates) by eliminating the flight derived biases for Isp, thrust and pc shift. It is to be noted that the assessment MR varies with PL; the controller MR is independent of PL.

The MR uncertainty as a function of PL is shown in ICD 13M15000, Space Shuttle Orbiter Vehicle/Main Engine Interface Control Document, Figure 4.2.2-3. The SSME operating characteristics from MPL to FPL are tabulated in Table 5.1. The nominal specific impulse and thrust as a function of altitude are plotted in ICD 13M15000, Figure 4.2.4-1. Deviations from Normal Power Level (NPL=104% RPL) are to be utilized only to control maximum dynamic pressure, limit the acceleration to 3 g's and thermal condition the engines for shutdown, or by special mission requirements.

The SSMEs can be commanded by Orbiter GN&C to power levels only within the range of MPL=65% RPL to FPL=109% RPL. However, MPS performance has not been verified beyond NPL (NPL=104% RPL for Phase II and Block I/IA SSMEs; NPL=104½% RPL for Block II/IIA SSMEs). Data in this section pertaining to FPL is for information only and should not be used for mission planning under normal or intact abort modes. In the event of a contingency abort, the flight rules allow manual selection of a maximum power level which may exceed NPL. The maximum allowed by the avionics is not the same for each flight, but is dependent on payload mass and other mission requirements. The throttling rate is 10%/sec at 1% increments of RPL with all engines throttled simultaneously. The 10%/sec throttle rate also holds for Block II/IIA SSMEs even though they operate at 104½% RPL when the 104% command is issued. For example, it takes 0.15 seconds to go from 103% to 104½%, and 0.05 seconds to go from 104½% to 105%. At all other power levels, the actual power level is equal to the commanded power level.

The SSMEs are capable of starting when provided with any engine inlet conditions (pressure and temperature) within the envelope as defined by ICD 13M15000, Figures 4.1-1 and 4.1-3, for the fuel and oxidizer, respectively. Engine propellant inlet conditions for mainstage operation are specified in ICD 13M15000, Figure 4.2.1-1. The minimum NPSP that the MPS propellant feed system is required to provide during steady-state mainstage operation is provided in ICD 13M15000, Figure 4.2.2-1. The

requirements for the MPS helium and nitrogen pneumatic system are provided in ICD 13M15000, Figure 5.1-3.

The SSMEs are capable of accelerating from the start signal to RPL as depicted in ICD 13M15000, Figure 4.1.4-1. This figure represents propulsion times only. The avionics delays associated with the issuance of the SSME start command from the Orbiter General Purpose Computers (GPCs), the SSME controller processing and initiation of the engine start, and the SSME controller reporting of the thrust level to the Orbiter GPCs are not included. EMR operation will be achieved within 6.5 seconds after engine start signal.

The predicted MPS propellant consumption and impulse for the integrated vehicle during the SSME start transient is given in Table 5.2.1. A more detailed breakdown, on an individual engine basis, is listed in Table 5.2.2.

The typical thrust decays (with dispersions) for MPL, RPL and FPL are presented in the SSME/Orbiter ICD (ICD 13M15000). Table 5.3 characterizes the per SSME propellant consumption and thrust impulse for shutdowns from six distinct power levels (MPL, 67% RPL, 91% RPL, RPL, NPL and FPL). Table 5.4.1 characterizes a nominal MECO shutdown from either MPL or 67% RPL. The chamber pressure, thrust impulse, and total propellant weight flows have been normalized based on the values listed in the notes section of the table, while thrust and propellant flowrates are based on either the MPL or 67% RPL tag values. Characteristic data for shutdowns at 91% RPL, RPL, NPL and FPL are tabulated in Tables 5.4.2 through 5.4.5, respectively. The 40 point (in time) data presented in these five tables are of a fidelity not required by ascent performance calculations and have been simulated by a very simplified curve presented in RI/Space Transportation System Division (STSD) IL FSD&P/FPA-87-116. Figure 5-14 depicts changes in thrust profile for shutdowns at various power levels.

The SSME characteristics derived during engine acceptance test are modified by Rocketdyne to account for changes that occur during engine usage. These changes include the plugging of LO_2 posts, enlarging boundary layer coolant holes, and updating the amount of nozzle leakage prior to each flight. These updated “Ground Based” tags are published in a NASA/MSFC letter and the values are placed into NSTS 08934, Space Shuttle Operational Databook. A set of correction factors are applied to these Ground Based tags to produce the assessment tags which are used for mission planning and flight margin assessment. The corrections were derived based on comparing the Ground Based tags with the official ascent performance reconstructions for missions STS-64 through STS-106 (excluding STS-78 and STS-93). Starting with the NPL (104.5% RPL for Block II/IIA engines) Ground Based tags, the corrections applied are:

a. Ground Based thrust tag + 1,398.61082 lb_f

b. Ground Based I_{sp} tag + 0.69511170 lb_f-sec/lb_m

c. Ground Based LH_2 flow rate (lb_m/sec) is not modified

d. GH_2 flow rate = 0.691279 lb_m/sec (STS-106 Baseline)

e. GO_2 flow rate = 1.914408 lb_m/sec (STS-106 Baseline)

f. LO_2 flow rate = (thrust/I_{sp}) - LH_2 + GO_2 + GH_2

These correction factors are specific for Block II/IIA SSMEs. No other types of engines are currently available for flight. Thus, data for the other SSME types is not included here. Update of the Ground Based-to-Assessment tags corrections is part of the annual MPS propellant inventory and performance update. All of the flights for that fiscal year are rolled into existing databases. Then propellant inventories and average assessment engine tags for the next calendar year's flights are generated. For missions where specific engines have not been assigned or for generic mission assignments, the average assessment engine tag values, Table 5.5.1 is used. The tags are for an equivalent controller MR of 6.032. The average Block II and Block IIA tags are the same, thus Table 5.5.1 data will be used for both of types. Due to the fact that tag values may now change from one use of an engine to the next, the individual assessment engine characteristics are no longer tabulated in this document. The flight-specific TDDP will be the sole source for engine-specific tag values.

5.2 ORBITAL MANEUVERING SYSTEM

The OMS provides the thrust to perform orbit insertion, orbit circularization, orbit transfer, rendezvous, deorbit, and launch aborts. In addition, the OMS engines can be used during second stage to provide up to an additional 400 pounds of ascent performance margin by burning up to 7,000 pounds of propellant. The typical design target is 250 pounds of ascent performance margin by burning 4,000 pounds of propellant. The information in this section is for reference use only. NSTS 08934 should be used to obtain current and official data.

The OMS is housed in two independent pods which also house the aft RCS subsystem. One OMS/RCS is located on each side of the aft fuselage. As depicted in Figure 5-15, the OMS in each pod consists of a pressure-fed, regeneratively cooled, gimbaled rocket engine, a fuel tank, an oxidizer tank, a propellant distribution subsystem, a high-pressure helium storage bottle, and tank pressurization regulators and controls. The integral OMS tankage is sized to provide propellant capacity for a ΔV of 1,000 fps with a payload of 65,000 pounds. The propellants are nitrogen tetroxide (N_2O_4) as the oxidizer and Monomethyl Hydrazine (MMH) as the fuel. Both OMS/RCS pods are shown schematically in Figure 5-16. Each OMS is designed to be fail safe.

The Orbiter Maneuvering Engine (OME) can be utilized singly by directing the thrust vector through the vehicle CG or together by directing the thrust vector of each engine

parallel to the other. In the event of losing the operation of an OME, a pod crossfeed line provides the capability of using the propellant remaining in both pods for operation of the remaining operable engine.

An interconnect between the OMS crossfeed line and the aft RCS manifolds allows 1000 pounds of OMS propellant per pod to be used by the RCS thrusters. For aborts, use of the OMS/RCS interconnect is permissible. Implementation of the interconnect requires eight seconds.

The nominal steady-state operational characteristics for a single or a pair of OMEs are provided in Table 5.6. The OMS specific impulse for nominal steady-state operation at vacuum conditions is specified at 313.2 seconds. Additional OME operational characteristics are:

a.	MR, Oxidizer-to-Fuel MR (O/F)	
	Nominal	1.65 ± 0.03
	Crossfeed	1.62 ± 0.03
b.	Chamber Pressure	
	Nominal	125 psia
	Operating Limits	113 to 143 psia
c.	Nozzle Area Ratio	55:1
d.	Minimum OME Firing Time	2 seconds
e.	Minimum Altitude for Safe Operation	70,000 feet
f.	Maximum Positive Longitudinal Acceleration for Safe Operation	3.0 g

The OME chamber pressure and thrust history during the ignition and shutdown transients are shown in Figures 5-17 and 5-18, respectively. The nominal time from onset of the electrical start command to 90% steady-state thrust is 450 ± 100 msec during which an impulse of 80 ± 50 lb/sec is produced. During shutdown, the nominal time from onset of the electrical shutdown command to 10% of the steady-state thrust is 900 ± 600 msec. The shutdown impulse from OFF signal to 2.3 seconds afterward is 2,700 ± 600 lb/sec. The minimum time between OFF signal and ON signal is 240 seconds for nominal operation and 30 seconds for launch abort.

The OMS geometric thrust vector misalignment requirement is defined in Figure 5-19. For all nominal and abort missions, the OMS engines remain at their stow positions during ascent.

5.3 REACTION CONTROL SYSTEM

The RCS employs 38 bipropellant primary thrusters and six vernier thrusters to provide attitude control and 3-axis translation during the ET separation, orbit insertion, on-orbit,

and entry phases of flight. The RCS thrusters also provide additional OMS propellant dump capability, if desired, during an ATO, TAL, or RTLS pre-MECO abort and roll control during ascent in the event of multiple SSME failures. The information in this section is for reference use only. NSTS 08934 should be used to obtain current and official data.

As shown in Figure 5-20, the RCS consists of three propulsion units, one in the forward module and one in each of the aft propulsion pods. Each RCS unit contains a propellant storage and distribution system, a helium pressurant gas storage, regulation, and distribution system to pressurize the propellant tanks, multiple thrusters, a thermal control system, and electrical and flight instrumentation systems. The helium pressurant is provided through redundant dual pressure regulators and check valves. A pressure relief system is provided to accommodate a dual regulator failure or excessive pressure rise. Propellant distribution manifolds are independently controlled by tank and manifold isolation valves providing propellant management capability and system redundancy.

The RCS propellant are N_2O_4 and MMH with a design MR of 1:6. The propellant capacity of the tanks in each module is 923 pounds of MMH and 1,464 pounds of N_2O_4 at 80°F.

As shown in Figure 5-21, the forward RCS module contains 14 primary and two vernier thrusters and each aft RCS module contains 12 primary and two vernier thrusters. The aft left and right hand RCS propellant systems are interconnected to the OMS propellant systems in each pod allowing the RCS thrusters to operate from the OMS propellant tanks or crossfeed propellants between the left and right-hand RCS pods. Figure 5-22 provides the thruster identification , direction of thruster plume and direction of vehicle motion. The nominal vacuum steady-state thrust correction factor (C_N) and propellant flow as a function of number of thrusters operating are providing in Tables 5.7 and 5.8 for the primary and vernier thrusters, respectively. Nominal thrust components, and SCARF and thrust angles, resultant thrust, thruster mount attach points, and application locations for all RCS thrusters are given in Table 5.9 and Figure 5-24. The MR and specific impulse for various RCS usage modes are listed in Table 5.10 and the thrust correction factor (C_A) for altitude for the primary thrusters is given in Figure 5-23.

Additional operating performance characteristics of the RCS thrusters are as follows:

	Primary Thruster	Vernier Thruster
a. Thrust		
1. 70,000 ft	823.5 lb ± 3%	Not applicable
2. Vacuum	870.0 lb ± 3%	24 lb ± 3%

b.	I_{sp} (Vacuum)		
	1. Nominal	280 sec	265 sec
	2. Minimum	276 sec	255 sec
c.	O/F MR	$1.6 + 0.032/-.048$	$1.6 + 0.072/-0.048$
d.	P_C (Nominal)	152 ± 4.5 psia	110 ± 4 psia
e.	Rise time to 90% thrust	50 msec	25 msec
f.	Decay time to 10% thrust	45 msec	20 msec
g.	Minimum impulse bit	65 ± 8 lb/sec	1.9 ± 0.6 lb/sec
h.	Firing Duration		0.080 to 0.320 sec
	1. Pulsing to		
	(a) On-orbit to 400,000 ft (FRCS, ARCS)	0.080 to 0.960 sec	0.080 to 0.320 sec
	(b) Entry (ARCS only)		
	to 125,000 ft	0.080 to 0.960 sec	
	to 70,000 ft	0.320 to 0.960 sec	
	to 45,000 ft	0.320 to 0.960 sec	
	2. Steady-state Nominal	1 to 150 sec	0.320 to 125 sec
	3. Contingency		0.320 to 125 sec
	(a) +X ARCS	1 to 800 sec	
	(b) −X FRCS	1 to 300 sec 2 thrusters only	
i.	Minimum On-time		
	1. to 125,000 ft	80 msec	
	2. to 70,000 ft	320 msec	
	3. to 45,000 ft (ARCS)	320 msec	
j.	Minimum Altitude		Not applicable
	1. FRCS*		
	(a) Ascent and Abort	165,000 ft	
	(b) On-orbit and Entry	400,000 ft	
	2. ARCS		

(a) Yaw thrusters 70,000 ft**

(b) All others 165,000 ft

*A minimum altitude constraint of 125,000 feet is applicable to the following thruster(s) firing(s):

Position	Dash No.	S/N
FIL	– 0413	112
F3L	– 0123	111
F1D	– 0116	104
F2D	– 0136	106
F2R	– 0434	114
F2U	– 0435	110
F3U	– 0425	108
F1F	– 0412	102

**45,000 feet with minimum propellant temperature of 70°F and 4-second burn time on dormant manifolds prior to 70,000 feet

5.4 REUSABLE SOLID ROCKET MOTOR (RSRM)

The two RSRMs provide the primary propulsive thrust for the Space Shuttle launch vehicle during most of the first stage of ascent. They are ignited after verification that each of the three SSMEs have achieved 90% RPL. The RSRM ignition command is normally issued 6.6 seconds after the SSME-3 ignition command for launches from KSC Pads 39A and 39B. Each RSRM produces a peak thrust over 3.0 million pounds during launch.

As illustrated in Figure 5-25, the RSRM is the primary element of each SRB and consists of an insulated case, propellant, igniter, and nozzle. A High Performance Motor (HPM) was developed as the baseline motor for the Space Shuttle beginning with STS-8. This was achieved by increasing the nozzle expansion ratio from 7.16:1 to 7.72:1, partially removing the aft inhibitors on the two center segment propellant grains, and increasing the propellant burn rate. The RSRM is an HPM with new segmented joint modifications.

At launch, more than 85% of the weight of each SRB is due to propellant consisting of an ammonium perchlorate oxidizer, aluminum, iron oxide as a catalyst, Polybutadiene Acrylonitrile (PBAN) polymer as a binder, and an epoxy curing agent. Characteristics of the propellant are summarized in Table 5.11. The propellant grain is an 11-point star-shaped perforation in the forward motor segment and a truncated-cone perforation in each of the aft segments and aft closure. This configuration provides high thrust at

ignition, then reduces the thrust by approximately a third 50 seconds after lift-off during the maximum dynamic pressure region of ascent.

The nozzle is a convergent-divergent nozzle with an aft pivot point flexible bearing allowing an all-axis gimballing capability of ± 8 degrees for thrust vector control. Each nozzle has a carbon cloth liner which chars and erodes during firing. Characteristics of the nozzle are listed in Table 5.12. The thrust vector alignment requirement is defined by Figures 5-26 and 5-27.

The vacuum thrust and impulse requirements for nominal RSRM performance at a Propellant Mean Bulk Temperature (PMBT) of 60°F are presented in Figure 5-28. The minimum impulse gate at 20 seconds and the minimum impulse gate at action time are defined as the nominal -2.0% and the nominal -1.0% respectively. The $\pm 3\sigma$ tolerance requirements for other performance parameters are listed in Table 5.13. The predicted PMBT versus day of the year at Eastern Test Range (ETR) is tabulated in Table 5.14. Table 5.14 is based on the global thermal model using the ambient temperatures in Appendix E. If the thrust, burn rate and specific impulse history of an RSRM at a given PMBT is known, the thrust, burn rate and specific impulse history at a different PMBT can be estimated using the equations in Table 5.16. The current target burn rate at ETR is 0.368 inch/sec at a PMBT of 60°F and 625 psia chamber pressure. The design range of propellant PMBT and the validity range for the RSRM performance requirements is 40°F to 90°F. For the purposes of systems analysis and generation of design/certification environments, the PMBT range of 50°F to 82°F shall be used (reference NSTS 07700, Volume X - Book 1, Space Shuttle Flight and Ground System Specification, Requirements, Paragraph 3.3.2.1.2).

The nominal and $\pm 3\sigma$ tolerance requirements for the RSRM are:

a.	Pressure Rise Rate	90.8 ± 25.1 psi/10 msec
b.	Thrust Rise Rate	$252{,}000 \pm 98{,}000$ lb/msec
c.	Ignition Interval	232 ± 30 msec $+40$ msec for environmental aging
d.	Maximum Thrust Imbalance	
	1. Ignition (Ballistics/Avionics)	470,000 lb_f (see Figure 5-29)
	2. Steady-state (Time = 1.0 sec)	85,000 lb_f until 60 seconds. Ramps up to 120,000 lb_f at 65 seconds and remains at 120,000 lb_f until tail-off.
	3. Tail-off	See NSTS 07700, Volume X - Book 1 Paragraph 3.3.2.1.2

The Shuttle Vehicle Booster (SVB) ignition model criteria are as follows:

a. A 40 msec time delay for environment/aging effects allows the late ignition interval to increase to 302 msec.

b. The RSRM ignition model is identified in the CMMD, as CMM-00030 in CMM Listings.

c. The SVB ignition model is based upon the system assessment thrust-time trace designated as the 'Block II' performance prediction.

d. The SVB ignition model pressure rise rate envelope is based upon eight RSRM motors which represent the family of pressure rise rate signatures. These are DM-2, STS-2R, STS-3L, STS-5L, STS-6R, STS-8R, STS-9L, and STS-11L.

e. The maximum/minimum pressure rise rate envelope generated by the SVB ignition model is shown in Figure 5-30.

The single motor performance time history for the RSRM, designated as TP-R074-99, at a PMBT of 60°F is given in Table 5.18. This table represents a revision that was made to the HPM performance baseline to reflect performance changes consistent with design modifications in the RSRM. The time-history of the nominal and uncertainty limits for the RSRM thrust for this baseline is given in Table 5.19. A performance summary for the block motor at a PMBT of 70°F is provided in Table 5.22.1 for the T-Delay Initialization Load (I-Load) values of 4.42 seconds.

In order to further improve Shuttle ascent flight performance predictions, the RSRM flight performance predictions have been modified based on trajectory reconstruction results from analysis and flight data. These modifications consist of the following:

a. Reducing the SRB thrust versus time profile at all time points by 1.10738%

b. Adjust the SRB thrust by the increments as specified in Table 5.20

The adjusted data are designated as "Adjusted RSRM Block Motor Predictions" and the adjusted performance summary at a PMBT of 70°F is provided in Table 5.23.2 for the T-Delay I-Load value of 4.42 seconds. A complete digital data set for the adjusted RSRM block motor is stored in the computer files identified in the CMMD, as CMM-00158 in CMM Listings. Modifications of the RSRM Block thrust-time data for PMBT, burn rate, and propellant weight may be accomplished using the equations listed in Table 5.24 with the updated TDDP for the particular mission and the current issue of NSTS 08934.

Previous RSRM performance model data are given in Appendix D for historic reference.

The SSP has provided for two RSRM thrust models. One, outlined in Paragraph 5.4.1, is the steady-state and tail-off thrust model used for GN&C first stage analyses. It is formally known as Fmodel. The second thrust model available, described in Paragraph 5.4.2, is used primarily for GN&C SRB separation analyses. It is a low-pressure model that traces the RSRM thrust from the SRB separation cue of PC=50 psia to 20 seconds after the cue.

5.4.1 Description of FModel6 RSRM Steady-state and Tail-off Thrust Model

The SVB steady-state and tail-off model criteria are as follows:

a. The RSRM tail-off model is identified in the CMMD, as CMM-00116 in CMM Listings.

b. The nominal and ± 3-sigma input values were computed from flight and ground test data through STS-61 and are as follows:

1.	Nozzle Throat Erosion Rate	0.00838 ± 0.00068 in/sec
2.	Nozzle Exit Plane Erosion Rate	0.001621 ± 0.00075 in/sec
3.	Burn Rate Variations (without TDDP data)	0.3680 ± 0.0071 in/sec
4.	Burn Rate Variations (with TDDP data)	(0.363 - 0.373) ± 0.0051 in/sec
5.	Burn Rate Variations Between Motors	0.0 ± 0.0038 in/sec
6.	Pressure Transducer Uncertainty	0.0 ± 5.0 psia
7.	PMBT Uncertainty	± 9°F
8.	PMBT Variations Between Motors	0.0 ± 1.5°F

c. The input shapes for the models are from 68 RSRM flight motors. These motors have been normalized to a .368 in/sec burn rate and 60°F PMBT. These motors are:

STS26A	STS26B	STS27A	STS27B	STS28A	STS28B
STS29A	STS29B	STS30A	STS30B	STS31A	STS31B
STS32A	STS32B	STS33A	STS33B	STS34A	STS34B
STS35A	STS35B	STS36A	STS36B	STS37A	STS37B
STS38A	STS38B	STS39A	STS39B	STS40A	STS40B

STS41A	STS41B	STS42A	STS42B	STS43A	STS43B
STS44A	STS44B	STS45A	STS45B	STS46A	STS46B
STS47A	STS47B	STS48A	STS48B	STS49A	STS49B
STS50A	STS50B	STS51A	STS51B	STS52A	STS52B
STS53A	STS53B	STS54A	STS54B	STS55A	STS55B
STS56A	STS56B	STS57A	STS57B	STS58A	STS58B
STS61A	STS61B				

d. The 3-sigma thrust differential envelope generated by the SVB tail-off model matches the Table 3.3.2.1.2c of NSTS 07700, Volume X - Book 1.

When using the tail-off model for GN&C analysis, a pseudo “Monte Carlo” technique is used. One hundred fifty seeds are selected which will envelope the NSTS 07700, Volume X, Space Shuttle Flight and Ground System Specification, thrust differential limits for steady-state and tail-off. The inputs consist of the TDDP PMBT and burn rates, and a seed for the random number generator. First a flight motor pair is randomly selected from the 34 pairs available. The random transducer errors are applied to each motors’ input data set. Then a random variation from the TDDP PMBT is calculated. The PMBT variation between motors is calculated. Next, the random sigma value for the burn rate variation from nominal is calculated to give a burn rate for the first motor, and then the random sigma value for the burn rate variation between motors is calculated to give the burn rate for the second motor. Finally, random sigma values are determined for the nozzle and exit plane erosion rate for both motors. The model then builds pairs of SRBs from these random selections.

5.4.2 Description of Low-pressure RSRM Tail-off Thrust Model

The low-pressure RSRM thrust tail-off model was developed from the 104 RSRM flight motors (STS-26 through STS-77) and the 17 HPM motors and is based on the following criteria:

a. The low-pressure RSRM tail-off model used for SRB separation analyses is identified in the CMMD, as CMM-00189 in CMM Listings.

b. Actual firings of the motors were normalized to 82°F with a 0.373 ips burn rate and to 50°F with 0.363 ips burn rate to define the minimum and maximum mean thrust traces, respectively.

c. The ±3-sigma input values were developed from the following:

1. PMBT Uncertainty — 9°F
2. Burn Rate Scale Factor Uncertainty — 0.368 ± 0.0059 in/sec
3. F/P Conversion Factor Uncertainty — 4088 ± 2.2% lb/psi
4. The shape factor term for the model, found in Table 5.25, was developed by enveloping and smoothing the combined 82°F/0.373 ips and 50°F/0.363 ips thrust traces. Also included in the shape factor term was K-sigma uncertainty applied at each time step.

The 3-sigma dispersed thrust is determined from the mean thrust for either hot (82°F) or cold (50°F) RSRM PMBT dispersed limits at SRB separation which is combined with four additional dispersions. These are the RSRM thrust dispersion (shape), thrust/chamber pressure (F/P) uncertainty, PMBT uncertainty, and the burn rate uncertainty. The mean thrust and shape factor are determined from Table 5.25 by interpolation to the required SRB separation timer value. The equations defining these dispersions and the method for their combination is as follows:

$$F_{THRUST} = F_{MEAN} \pm \sqrt{(R_1 * F_{SHAPE})^2 + (R_2 * F_{F/P})^2 + (R_3 * F_{PMBT})^2 + (R_4 * F_{SCALE_FACTOR})^2}$$

where:

F_{MEAN} = mean thrust at either 82°($F_{82\ DEG}$) for hot RSRMs or 50°F ($F_{50\ DEG}$) for cold RSRMs from Table 5.25;
the ± provides for positive and negative dispersions, respectively;
F_{SHAPE} = Shape-Factor/3 from Table 5.25 which is the RSRM thrust dispersion;
$F_{F/P}$ = 0.022/3 * F_{MEAN} is the RSRM Thrust/Pressure uncertainty;
F_{PMBT} = 0.010/3 * F_{MEAN} is RSRM PMBT uncertainty;
F_{SCALE_FACTOR} = 0.026/3 * F_{MEAN} is the RSRM burn rate uncertainty;
R_i are random seeds between 0 and 3 for these dispersions:
R_1 = RSRM thrust dispersion sigma level,
R_2 = RSRM F/P (Thrust/Pressure) uncertainty sigma level,
R_3 = RSRM PMBT uncertainty sigma level, and R_4 = RSRM burn rate uncertainty sigma level.

Thrust values of zero should be used for all cases where the above equation results in a value less than zero.

5.5 BOOSTER SEPARATION MOTOR (BSM)

The BSMs provide the lateral force required to accelerate the SRBs away from the Orbiter/External Tank after SRB burnout. There are eight BSMs on each SRB comprising a total of 16. These BSMs are grouped in two clusters of four and are located in

the forward frustum and on the aft skirts of the SRBs. The SRB separation command that fires the SRB/ET attach bolts, also ignites the BSMs. The BSM performance criteria are outlined in NSTS 07700, Volume X - Book 1, Paragraph 3.2.1.1.9.1.1.3 and in the CMMD, as CMM-00193 in CMM Listings.

The MSFC database of Lot Acceptance Tests of BSMs was used to create BSM thrust models defined for the PMBT range from 30°F to 120°F that are shown in Figures 5.5-1 to 5.5-5. These models include nominal, ± 1, and ± 3-sigma values.

The MSFC SRB Project supplied BSM model was adjusted for an additional 10% margin in thrust at 100°F for the aft cluster and 110°F for the forward cluster PMBT as shown in Figures 5.5-6 and 5.5-7. This adjusted model is used for SRB separation certification.

For mission-specific analysis purposes, there are two equations (for time and thrust) used to scale down the mission specific BSM thrust from 120°F PMBT thrust profile to the mission specific PMBT. The equations are as follows:

Time (sec) $T_2 = T_1 * EXP(\pi_k * (\text{New Temperature} - 120))$

Thrust (lbs) $F_2 = F_1 * EXP(\pi_k * (\text{New Temperature} - 120))$

where $\pi_K = 0.0117°F^{-1}$, per MS4-96-078, dated 27 Sep 96

TABLE 5.1

SSME OPERATIONAL CHARACTERISTICS

		SEA LEVEL	VACUUM
Thrust (per engine) (pounds)	FPL	417,300	512,300
	NPL	390,000	488,800
	RPL	375,000	470,000
	MPL	*	305,500
Specific Impulse (lb_f*$_{sec}$/lb_m)	FPL	≥ 369.0	≥ 452.9
	NPL	≥ 364.8	≥ 452.9
	RPL	≥ 361.4	≥ 452.9
	MPL	*	≥ 451.3

*The SSME cannot operate below 90% RPL at sea level due to flow separation in the nozzle

TABLE 5.2 (DELETED)

TABLE 5.2.1

SSME START TRANSIENT PREDICTIONS FOR ALL THREE ENGINES

PARAMETER	VALUE
LO_2 Consumption to SRB ignition	9,534.1 lb_m*
LH_2 Consumption to SRB ignition	1,795.8 lb_m*
Thrust at SRB ignition	1,126,403 lb_f
Thrust Impulse to SRB ignition	3,857,656 lb_f-sec

SOURCE: STS-106 baseline update, PRCBD No. S084799AE, dated 5/2/01

*The first 58 pounds of LH_2 and 172 pounds of LO_2 across the interface are used to prime the engine and do not go overboard, nor are the fluids converted to pressurant gases.

TABLE 5.2.2

SSME START TRANSIENT PREDICTION VERSUS TIME, INDIVIDUAL SSMEs

Time from engine start command, secs	Main combustion chamber pressure[a]	Thrust[b]	Thrust impulse[c]	LH_2 flow rate[d]	Total LH_2 flow rate[e]	LO_2 flow rate[f]	Total LO_2 flow rate[g]
0.0000	0.00542	0.00000	0.000000	0.0000	0.00000	0.00000	0.00000
0.0625	0.00543	0.00006	0.000040	0.0345	0.00035	0.00025	0.00000
0.5000	0.00548	0.00009	0.000317	0.0347	0.00384	0.00327	0.00017
0.6250	0.00557	0.00016	0.000397	0.0455	0.0050	0.00348	0.00029
0.8125	0.00580	0.00015	0.000518	0.0461	0.0070	0.00459	0.00048
1.0000	0.00998	0.00236	0.000639	0.1244	0.0103	0.00921	0.00080
1.2187	0.0178	0.00376	0.000815	0.0719	0.0155	0.0618	0.0029
1.3750	0.0227	0.00712	0.00105	0.2443	0.0216	0.0993	0.0062
1.4687	0.0510	0.00916	0.00127	0.2041	0.0264	0.1217	0.0091
1.5937	0.1418	0.0113	0.00162	0.3828	0.0350	0.1257	0.0132
1.7187	0.1777	0.0179	0.00208	0.3353	0.0453	0.1445	0.0177
1.8437	0.2170	0.0803	0.00412	0.4667	0.0566	0.1650	0.0229
1.9375	0.2496	0.0983	0.00645	0.5256	0.0675	0.1803	0.0271
2.0937	0.2788	0.1326	0.0116	0.5447	0.0869	0.2179	0.0352
2.2187	0.2847	0.1489	0.0166	0.5336	0.1025	0.2428	0.0427
2.4062	0.2876	0.1574	0.0247	0.5239	0.1254	0.2528	0.0551
2.6250	0.3788	0.2311	0.0362	0.7318	0.1566	0.3254	0.0715
2.6875	0.4102	0.2608	0.0406	0.7450	0.1673	0.3579	0.0773
2.9375	0.4774	0.3401	0.0619	0.6725	0.2079	0.4443	0.1042
3.2500	0.6520	0.5528	0.1002	0.7561	0.2594	0.6327	0.1488
3.3750	0.7312	0.6243	0.1211	0.7389	0.2810	0.7115	0.1713
3.5937	0.8034	0.7639	0.1626	0.8253	0.3199	0.8017	0.2146
3.6562	0.8446	0.8202	0.1770	0.8588	0.3321	0.8446	0.2287
3.7187	0.8863	0.8762	0.1915	0.8812	0.3446	0.8877	0.2430
3.8125	0.9186	0.9161	0.2153	0.9004	0.3639	0.9207	0.2659
4.0000	0.9552	0.9561	0.2647	0.9429	0.4038	0.9526	0.3129
4.2500	0.9916	0.9987	0.3337	0.9828	0.4595	0.9866	0.3778
4.7500	1.0057	1.0116	0.4756	0.9921	0.5738	0.9989	0.5105
5.0000	1.0075	1.0128	0.5469	0.9943	0.6311	1.00065	0.5771
5.0625	1.0072	1.0123	0.5646	0.9956	0.6455	1.00064	0.5936
5.0937	1.0070	1.0121	0.5735	0.9939	0.6527	1.00063	0.6018
5.1250	1.0069	1.0119	0.5823	0.9947	0.6598	1.00063	0.6100
5.1562	1.0067	1.0116	0.5912	0.9958	0.6670	1.00062	0.6183
5.1875	1.0066	1.0114	0.6000	0.9952	0.6742	1.00061	0.6265
5.2500	1.0063	1.0110	0.6177	0.9966	0.6886	1.00060	0.6430

TABLE 5.2.2

SSME START TRANSIENT PREDICTION VERSUS TIME, INDIVIDUAL SSMEs - Concluded

Time from engine start command, sec	Main combustion chamber pressure[a]	Thrust[b]	Thrust impulse[c]	LH_2 flow rate[d]	Total LH_2 flow rate[e]	LO_2 flow rate[f]	Total LO_2 flow rate[g]
5.2812	1.0062	1.0107	0.6266	1.0000	0.6958	1.00059	0.6512
6.3600	1.0011	1.0030	0.9323	1.0000	0.9446	1.00036	0.9369
6.4800	1.0006	1.0021	0.9662	1.0000	0.9723	1.00033	0.9684
6.6000	1.0000	1.0013	1.0000	1.0000	1.0000	1.00030	1.0000
8.0000	1.0000	1.0000	1.3942	1.0000	1.3235	1.00000	1.3678

[a] Combustion chamber pressure at SRB ignition - 2,747.00 psia
[b] Thrust at SRB ignition - 100% RPL assessment tag value, lb_f
[c] Total thrust impulse to SRB ignition - 1,330,922.71 lb_f-sec
[d] LH_2 flow rate at SRB ignition - 100% RPL assessment tag value, lb_m/sec
[e] Total LH_2 consumption to SRB ignition - 615.65 lb_m
[f] LO_2 flow rate at SRB ignition - 100% RPL assessment tag value, lb_m/sec
[g] Total LO_2 consumption to SRB ignition - 3,281.64 lb_m

TABLE 5.3

SSME SHUTDOWN TRANSIENT PREDICTION FOR EACH ENGINE

Parameter	Condition					
	MPL (65% RPL)	67% of RPL	91% of RPL	RPL	NPL (104.5% RPL)	FPL[a] (109% RPL)
LO_2 Consumption, lb_m	449.4	467.3	681.6	762.0	802.2	842.4
LH_2 Consumption, lb_m	224.5	229.9	295.2	319.7	332.0	344.2
Impulse, lb_f-sec	277,767	282,758	355,258	389,195	406,942	425,700

SOURCE: STS-106 baseline update, PRCBD No. S084799AE, dated 5/2/01

[a] Block II/IIA engine not certified above 104.5%

TABLE 5.4 (DELETED)

TABLE 5.4.1

SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM MPL (65% RPL) AND 67% RPL

Time from engine shutdown command, secs	Main combustion chamber pressure[a]	Thrust[b]	Thrust impulse[c]	LH_2 flow rate[d]	Total LH_2 flow[e]	LO_2 flow rate[f]	Total LO_2 flow[g]
0.0000	1.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000
0.0625	0.9932	0.9934	0.0697	0.9945	0.0316	0.9933	0.0824
0.2187	0.8415	0.8356	0.2302	0.8860	0.1063	0.8358	0.2724
0.3437	0.6673	0.6573	0.3344	0.7446	0.1578	0.6578	0.3958
0.4062	0.5986	0.5860	0.3771	0.6941	0.1803	0.5867	0.4463
0.5312	0.5092	0.4950	0.4519	0.6151	0.2216	0.4963	0.5350
0.5625	0.4949	0.4813	0.4688	0.5962	0.2311	0.4829	0.5550
0.5937	0.4807	0.4677	0.4856	0.5773	0.2406	0.4695	0.5749
0.8125	0.3970	0.3902	0.5886	0.4442	0.2966	0.3948	0.6978
1.0000	0.3353	0.3312	0.6637	0.3642	0.3351	0.3366	0.7878
1.1875	0.2657	0.2602	0.7260	0.3096	0.3669	0.2652	0.8629
1.2500	0.2417	0.2350	0.7444	0.2972	0.3768	0.2396	0.8850
1.3750	0.2093	0.2000	0.7743	0.2992	0.3956	0.2017	0.9208
1.4375	0.1915	0.1809	0.7878	0.3092	0.4052	0.1795	0.9369
1.5937	0.1447	0.1316	0.8148	0.3738	0.4319	0.1147	0.9670
1.6250	0.1393	0.1261	0.8193	0.3843	0.4378	0.1067	0.9717
1.7500	0.1156	0.1030	0.8352	0.4370	0.4638	0.0550	0.9853
1.8125	0.1032	0.0912	0.8420	0.4633	0.4779	0.0401	0.9893
1.9375	0.0890	0.0782	0.8538	0.4885	0.5082	0.0126	0.9934
2.1875	0.0620	0.0543	0.8722	0.4549	0.5678	0.0083	0.9963
2.2500	0.0578	0.0506	0.8759	0.4636	0.5823	0.0083	0.9970
2.3437	0.0542	0.0474	0.8810	0.4660	0.6043	0.0083	0.9980
2.3750	0.0536	0.0468	0.8826	0.4661	0.6117	0.0083	0.9984
2.5000	0.0540	0.0472	0.8891	0.4615	0.6410	0.0052	0.9996
2.7500	0.0482	0.0421	0.9019	0.4179	0.6966	0.0000	1.0000
3.0000	0.0384	0.0336	0.9124	0.3705	0.7464	0.0000	1.0000
3.5000	0.0312	0.0272	0.9290	0.2744	0.8275	0.0000	1.0000
4.0000	0.0288	0.0252	0.9435	0.2160	0.8889	0.0000	1.0000
4.2500	0.0280	0.0245	0.9504	0.1984	0.9149	0.0000	1.0000
4.5000	0.0275	0.0242	0.9573	0.1716	0.9385	0.0000	1.0000
4.6250	0.0271	0.0240	0.9606	0.1483	0.9490	0.0000	1.0000

TABLE 5.4.1

SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM MPL (65% RPL) AND 67% RPL - Concluded

Time from engine shutdown command, secs	Main combustion chamber pressure[a]	Thrust[b]	Thrust impulse[c]	LH_2 flow rate[d]	Total LH_2 flow[e]	LO_2 flow rate[f]	Total LO_2 flow[g]
4.7500	0.0266	0.0237	0.9640	0.1243	0.9575	0.0000	1.0000
4.8750	0.0261	0.0235	0.9673	0.1013	0.9645	0.0000	1.0000
5.0000	0.0257	0.0234	0.9705	0.0788	0.9706	0.0000	1.0000
5.1250	0.0250	0.0228	0.9736	0.0787	0.9754	0.0000	1.0000
5.2500	0.0242	0.0221	0.9767	0.0786	0.9802	0.0000	1.0000
7.0000	0.0091	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
7.1250	0.0045	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
7.2500	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
8.0000	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

NOTES:

	65% RPL	67% RPL	Units
[a] Combustion chamber pressure at MECO command	1,785.55	1,840.49	psia
[b] Thrust at MECO command	MPL tag	67% tag	lb_f
[c] Total shutdown thrust impulse	277,767	282,758	lb_f-sec
[d] LH_2 flow rate at MECO command	MPL tag	67% tag	lb_m/sec
[e] Total LH_2 shutdown flow	224.47	229.92	lb_m
[f] LO_2 flow rate at MECO command	MPL tag	67% tag	lb_m/sec
[g] Total LO_2 shutdown flow	449.41	467.28	lb_m

TABLE 5.4.2

SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM 91% RPL

Time from engine shutdown command, sec	Main combustion chamber[a] pressure	Thrust[b]	Thrust impulse[c]	LH_2 flow rate[d]	Total LH_2 flow[e]	LO_2 flow rate[f]	Total LO_2 flow[g]
0.00	1.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000
0.08	0.9810	0.9794	0.0894	0.9924	0.0386	0.9792	0.1038
0.20	0.8879	0.8846	0.2159	0.9117	0.0945	0.8847	0.2505
0.48	0.5721	0.5561	0.4425	0.7048	0.2017	0.5527	0.5128
0.64	0.4581	0.4431	0.5319	0.5947	0.2528	0.4389	0.6156
0.84	0.3781	0.3639	0.6218	0.5101	0.3062	0.3600	0.7190
1.00	0.3326	0.3185	0.6830	0.4722	0.3446	0.3136	0.7891
1.24	0.2694	0.2546	0.7605	0.4423	0.3978	0.2452	0.8768
1.32	0.2488	0.2342	0.7825	0.4291	0.4147	0.2236	0.9014
1.40	0.2262	0.2114	0.8026	0.4162	0.4312	0.1994	0.9235
1.48	0.1963	0.1815	0.8204	0.4058	0.4472	0.1666	0.9428
1.64	0.1282	0.1151	0.8466	0.4117	0.4789	0.0864	0.9687
1.76	0.0946	0.0835	0.8599	0.4331	0.5034	0.0397	0.9787
1.92	0.0739	0.0648	0.8733	0.4769	0.5389	0.0232	0.9844
1.96	0.0668	0.0586	0.8760	0.4866	0.5483	0.0206	0.9855
2.08	0.0597	0.0523	0.8835	0.5167	0.5776	0.0158	0.9883
2.12	0.0605	0.0530	0.8859	0.5186	0.5876	0.0171	0.9892
2.20	0.0562	0.0493	0.8905	0.5228	0.6079	0.0194	0.9911
2.40	0.0575	0.0503	0.9013	0.5049	0.6578	0.0199	0.9962
2.48	0.0607	0.0531	0.9060	0.4902	0.6771	0.0195	0.9983
2.56	0.0597	0.0522	0.9107	0.4862	0.6960	0.0062	0.99985
2.64	0.0596	0.0521	0.9154	0.4813	0.7148	0.0000	1.0000
2.80	0.0567	0.0497	0.9245	0.4624	0.7514	0.0000	1.0000
3.00	0.0542	0.0475	0.9353	0.4126	0.7933	0.0000	1.0000
3.28	0.0427	0.0373	0.9487	0.3241	0.8435	0.0000	1.0000
3.52	0.0313	0.0274	0.9592	0.2652	0.8777	0.0000	1.0000
4.40	0.0205	0.0177	0.9792	0.1482	0.9647	0.0000	1.0000
4.52	0.0202	0.0177	0.9816	0.1287	0.9727	0.0000	1.0000
4.76	0.0167	0.0146	0.9861	0.0881	0.9856	0.0000	1.0000
4.88	0.0142	0.0125	0.9879	0.0630	0.9903	0.0000	1.0000
5.00	0.0113	0.0098	0.9895	0.0601	0.9939	0.0000	1.0000
5.08	0.0117	0.0103	0.9904	0.0391	0.9958	0.0000	1.0000
5.28	0.0086	0.0075	0.9924	0.0000	1.0000	0.0000	1.0000

TABLE 5.4.2

SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM 91% RPL - Concluded

Time from engine shutdown command, sec	Main combustion chamber[a] pressure	Thrust[b]	Thrust impulse[c]	LH_2 flow rate[d]	Total LH_2 flow[e]	LO_2 flow rate[f]	Total LO_2 flow[g]
5.32	0.0084	0.0073	0.9927	0.0000	1.0000	0.0000	1.0000
5.48	0.0080	0.0070	0.9940	0.0000	1.0000	0.0000	1.0000
5.56	0.0083	0.0072	0.9946	0.0000	1.0000	0.0000	1.0000
6.00	0.0042	0.0037	0.9971	0.0000	1.0000	0.0000	1.0000
7.20	0.0015	0.0014	0.99997	0.0000	1.0000	0.0000	1.0000
7.24	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
8.00	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

[a] Combustion chamber pressure at MECO command - 2,499.77 psia
[b] Thrust at MECO command - 91% RPL assessment tag value lbf
[c] Total shutdown thrust impulse - 355,258 lb_f-sec
[d] LH_2 flow rate at MECO command - 91% RPL assessment tag value lb_m/sec
[e] Total LH_2 shutdown flow - 295.24 lb_m
[f] LO_2 flow rate at MECO command - 91% RPL assessment tag value lb_m/sec
[g] Total LO_2 shutdown flow - 681.63 lb_m

TABLE 5.4.2.1 (DELETED)

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TABLE 5.4.3

SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM RPL

Time from engine shutdown command, sec	Main combustion chamber[a] pressure	Thrust[b]	Thrust impulse[c]	LH_2 flow rate[d]	Total LH_2 flow[e]	LO_2 flow rate[f]	Total LO_2 flow[g]
0.00	1.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000
0.08	0.9862	0.9852	0.0900	0.9931	0.0390	0.9851	0.1028
0.20	0.9053	0.9039	0.2187	0.9152	0.0953	0.9042	0.2498
0.48	0.5969	0.5803	0.4550	0.7334	0.2063	0.5764	0.5195
0.64	0.4626	0.4443	0.5471	0.6305	0.2603	0.4377	0.6235
0.84	0.3806	0.3644	0.6374	0.5340	0.3166	0.3585	0.7251
1.00	0.3367	0.3199	0.6990	0.5068	0.3575	0.3121	0.7941
1.24	0.2753	0.2573	0.7773	0.4903	0.4157	0.2435	0.8802
1.32	0.2559	0.2380	0.7997	0.4826	0.4347	0.2223	0.9043
1.40	0.2333	0.2161	0.8203	0.4624	0.4533	0.1994	0.9261
1.48	0.2050	0.1884	0.8387	0.4479	0.4711	0.1690	0.9454
1.64	0.1298	0.1163	0.8658	0.4290	0.5052	0.0848	0.9711
1.76	0.0941	0.0831	0.8792	0.4334	0.5305	0.0426	0.9808
1.92	0.0690	0.0604	0.8921	0.4626	0.5656	0.0203	0.9861
1.96	0.0608	0.0533	0.8947	0.4699	0.5748	0.0203	0.9871
2.08	0.0533	0.0467	0.9014	0.4921	0.6031	0.0139	0.9897
2.12	0.0539	0.0472	0.9036	0.4917	0.6127	0.0139	0.9905
2.20	0.0470	0.0412	0.9076	0.4894	0.6320	0.0170	0.9920
2.40	0.0477	0.0417	0.9165	0.4662	0.6789	0.0176	0.9964
2.48	0.0527	0.0461	0.9205	0.4498	0.6968	0.0171	0.9982
2.56	0.0521	0.0456	0.9246	0.4470	0.7144	0.0084	0.9998
2.64	0.0527	0.0461	0.9287	0.4439	0.7319	0.0000	1.0000
2.80	0.0514	0.0450	0.9369	0.4297	0.7661	0.0000	1.0000
3.00	0.0508	0.0445	0.9469	0.3852	0.8052	0.0000	1.0000
3.28	0.0396	0.0346	0.9597	0.3055	0.8530	0.0000	1.0000
3.52	0.0276	0.0242	0.9700	0.2410	0.8851	0.0000	1.0000
4.40	0.0176	0.0154	0.9869	0.1286	0.9648	0.0000	1.0000
4.52	0.0176	0.0154	0.9890	0.1172	0.9720	0.0000	1.0000
4.76	0.0138	0.0121	0.9930	0.0904	0.9843	0.0000	1.0000
4.88	0.0107	0.0094	0.9944	0.0567	0.9890	0.0000	1.0000
5.00	0.0076	0.0066	0.9956	0.0527	0.9923	0.0000	1.0000
5.08	0.0082	0.0072	0.9962	0.0527	0.9943	0.0000	1.0000
5.28	0.0051	0.0044	0.9975	0.0527	0.9995	0.0000	1.0000

TABLE 5.4.3

SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM RPL - Concluded

Time from engine shutdown command, sec	Main combustion chamber[a] pressure	Thrust[b]	Thrust impulse[c]	LH_2 flow rate[d]	Total LH_2 flow[e]	LO_2 flow rate[f]	Total LO_2 flow[g]
5.32	0.0051	0.0044	0.9977	0.0000	1.0000	0.0000	1.0000
5.48	0.0045	0.0039	0.9984	0.0000	1.0000	0.0000	1.0000
5.48	0.0045	0.0039	0.9984	0.0000	1.0000	0.0000	1.0000
5.56	0.0051	0.0044	0.9988	0.0000	1.0000	0.0000	1.0000
6.00	0.0007	0.00004	0.99994	0.0000	1.0000	0.0000	1.0000
7.20	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
7.24	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
8.00	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

[a] Combustion chamber pressure at MECO command - 2,747.00 psia
[b] Thrust at MECO command - RPL assessment tag value lb_f
[c] Total shutdown thrust impulse - 389,195 lb_f-sec
[d] LH_2 flow rate at MECO command - RPL assessment tag value lb_m/sec
[e] Total LH_2 shutdown flow - 319.73 lb_m
[f] LO_2 flow rate at MECO command - RPL assessment tag value lb_m/sec
[g] Total LO_2 shutdown flow - 762.02 lb_m

TABLE 5.4.4

SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM NPL (104% RPL)

Time from engine shutdown command, sec	Main combustion chamber[a] pressure	Thrust[b]	Thrust impulse[c]	LH_2 flow rate[d]	Total LH_2 flow[e]	LO_2 flow rate[f]	Total LO_2 flow[g]
0.00	1.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000
0.08	0.9918	0.9902	0.0853	1.0027	0.0394	0.9901	0.0975
0.20	0.9395	0.9381	0.2095	0.9488	0.0973	0.9383	0.2393
0.48	0.6716	0.6630	0.4515	0.7434	0.2131	0.6614	0.5156
0.64	0.5154	0.5007	0.5501	0.6423	0.2678	0.4970	0.6276
0.84	0.3809	0.3652	0.6414	0.5261	0.3249	0.3602	0.7308
1.00	0.3235	0.3090	0.6987	0.4802	0.3645	0.3026	0.7952
1.24	0.2686	0.2527	0.7711	0.4485	0.4188	0.2427	0.8755
1.32	0.2505	0.2346	0.7920	0.4384	0.4362	0.2234	0.8983
1.40	0.2297	0.2145	0.8113	0.4188	0.4531	0.2026	0.9192
1.48	0.2059	0.1908	0.8287	0.4081	0.4694	0.1767	0.9378
1.64	0.1399	0.1267	0.8557	0.3916	0.5005	0.1028	0.9648
1.76	0.1050	0.0938	0.8696	0.3883	0.5235	0.0629	0.9767
1.92	0.0763	0.0672	0.8831	0.4138	0.5550	0.0319	0.9849
1.96	0.0684	0.0613	0.8859	0.4221	0.5632	0.0288	0.9863
2.08	0.0597	0.0522	0.8931	0.4519	0.5890	0.0159	0.9891
2.12	0.0580	0.0507	0.8953	0.4545	0.5979	0.0159	0.9900
2.20	0.0501	0.0438	0.8993	0.4621	0.6160	0.0151	0.9915
2.40	0.0515	0.0449	0.9086	0.4501	0.6611	0.0167	0.9953
2.48	0.0547	0.0479	0.9125	0.4410	0.6786	0.0166	0.9969
2.56	0.0534	0.0467	0.9166	0.4335	0.6959	0.0118	0.9985
2.64	0.0530	0.0463	0.9205	0.4330	0.7129	0.0069	0.9992
2.80	0.0510	0.0446	0.9282	0.4188	0.7465	0.0000	1.0000
3.00	0.0499	0.0436	0.9376	0.3816	0.7853	0.0000	1.0000
3.28	0.0439	0.0383	0.9498	0.3230	0.8342	0.0000	1.0000
3.52	0.0349	0.0306	0.9599	0.2646	0.8690	0.0000	1.0000
4.40	0.0200	0.0174	0.9797	0.1416	0.9554	0.0000	1.0000
4.52	0.0195	0.0170	0.9818	0.1316	0.9635	0.0000	1.0000
4.76	0.0171	0.0149	0.9860	0.1103	0.9778	0.0000	1.0000
4.88	0.0148	0.0130	0.9877	0.0885	0.9838	0.0000	1.0000
5.00	0.0129	0.0112	0.9893	0.0733	0.9887	0.0000	1.0000
5.08	0.0122	0.0107	0.9902	0.0675	0.9915	0.0000	1.0000
5.28	0.0097	0.0084	0.9922	0.0511	0.9971	0.0000	1.0000

TABLE 5.4.4

SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM NPL (104% RPL) - Concluded

Time from engine shutdown command, sec	Main combustion chamber[a] pressure	Thrust[b]	Thrust impulse[c]	LH_2 flow rate[d]	Total LH_2 flow[e]	LO_2 flow rate[f]	Total LO_2 flow[g]
5.32	0.0092	0.0080	0.9926	0.0218	0.9979	0.0000	1.0000
5.48	0.0081	0.0071	0.9938	0.0000	1.0000	0.0000	1.0000
5.56	0.0084	0.0073	0.9944	0.0000	1.0000	0.0000	1.0000
6.00	0.0044	0.0039	0.9970	0.0000	1.0000	0.0000	1.0000
7.20	0.0023	0.0018	0.99996	0.0000	1.0000	0.0000	1.0000
7.24	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
8.00	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

[a] Combustion chamber pressure at MECO command - 2,870.62 psia
[b] Thrust at MECO command - 104% RPL assessment tag value lb_f
[c] Total shutdown thrust impulse - 406,942 lb_f-sec
[d] LH_2 flow rate at MECO command - 104% RPL assessment tag value lb_m/sec
[e] Total LH_2 shutdown flow - 331.98 lb_m
[f] LO_2 flow rate at MECO command - 104% RPL assessment tag value lb_m/sec
[g] Total LO_2 shutdown flow - 802.21 lb_m

TABLE 5.4.5

SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM FPL (109% RPL)

Time from engine shutdown command, sec	Main combustion chamber[a] pressure	Thrust[b]	Thrust impulse[c]	LH_2 flow rate[d]	Total LH_2 flow[e]	LO_2 flow rate[f]	Total LO_2 flow[g]
0.00	1.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000
0.08	0.9989	0.9965	0.0795	1.0146	0.0399	0.9963	0.0908
0.20	0.9822	0.9809	0.1980	0.9907	0.0997	0.9809	0.2261
0.48	0.7649	0.7664	0.4472	0.7559	0.2217	0.7676	0.5108
0.64	0.5814	0.5713	0.5538	0.6570	0.2771	0.5711	0.6327
0.84	0.3813	0.3663	0.6464	0.5162	0.3353	0.3624	0.7380
1.00	0.3096	0.2954	0.6983	0.4469	0.3733	0.2907	0.7965
1.24	0.2603	0.2470	0.7633	0.3963	0.4226	0.2418	0.8696
1.32	0.2437	0.2304	0.7824	0.3832	0.4381	0.2247	0.8908
1.40	0.2253	0.2125	0.8000	0.3643	0.4529	0.2065	0.9105
1.48	0.2070	0.1939	0.8162	0.3583	0.4673	0.1863	0.9283
1.64	0.1525	0.1397	0.8430	0.3448	0.4947	0.1253	0.9570
1.76	0.1186	0.1072	0.8576	0.3319	0.5148	0.0883	0.9715
1.92	0.0854	0.0757	0.8719	0.3527	0.5417	0.0464	0.9835
1.96	0.0778	0.0713	0.8748	0.3623	0.5488	0.0395	0.9854
2.08	0.0676	0.0591	0.8827	0.4016	0.5714	0.0185	0.9884
2.12	0.0631	0.0551	0.8849	0.4081	0.5794	0.0185	0.9893
2.20	0.0539	0.0470	0.8890	0.4279	0.5960	0.0127	0.9908
2.40	0.0562	0.0490	0.8987	0.4300	0.6389	0.0155	0.9939
2.48	0.0573	0.0501	0.9026	0.4300	0.6559	0.0160	0.9953
2.56	0.0550	0.0480	0.9065	0.4167	0.6727	0.0160	0.9968
2.64	0.0533	0.0465	0.9103	0.4193	0.6892	0.0156	0.9982
2.80	0.0505	0.0441	0.9174	0.4052	0.7221	0.0000	1.0000
3.00	0.0487	0.0425	0.9260	0.3770	0.7604	0.0000	1.0000
3.28	0.0493	0.0430	0.9374	0.3449	0.8107	0.0000	1.0000
3.52	0.0441	0.0385	0.9473	0.2941	0.8489	0.0000	1.0000
4.40	0.0229	0.0200	0.9706	0.1578	0.9436	0.0000	1.0000
4.52	0.0218	0.0190	0.9729	0.1497	0.9528	0.0000	1.0000
4.76	0.0212	0.0185	0.9773	0.1351	0.9696	0.0000	1.0000
4.88	0.0200	0.0175	0.9794	0.1282	0.9774	0.0000	1.0000
5.00	0.0195	0.0170	0.9815	0.0990	0.9843	0.0000	1.0000
5.08	0.0172	0.0150	0.9827	0.0861	0.9879	0.0000	1.0000
5.28	0.0155	0.0135	0.9856	0.0490	0.9942	0.0000	1.0000

TABLE 5.4.5

SSME SHUTDOWN TRANSIENT CHARACTERISTICS FROM FPL (109% RPL) - Concluded

Time from engine shutdown command, sec	Main combustion chamber[a] pressure	Thrust[b]	Thrust impulse[c]	LH_2 flow rate[d]	Total LH_2 flow[e]	LO_2 flow rate[f]	Total LO_2 flow[g]
5.32	0.0143	0.0125	0.9862	0.0490	0.9952	0.0000	1.0000
5.48	0.0126	0.0110	0.9881	0.0490	0.9991	0.0000	1.0000
5.56	0.0126	0.0110	0.9889	0.0000	1.0000	0.0000	1.0000
6.00	0.0091	0.0080	0.9933	0.0000	1.0000	0.0000	1.0000
7.20	0.0046	0.0040	0.99992	0.0000	1.0000	0.0000	1.0000
7.24	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
8.00	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

[a] Combustion chamber pressure at MECO command - 2,994.23 psia
[b] Thrust at MECO command - 109% RPL assessment tag value lb_f
[c] Total shutdown thrust impulse - 425,700 lb_f/sec
[d] LH_2 flow rate at MECO command - 109% RPL assessment tag value lb_m/sec
[e] Total LH_2 shutdown flow - 344.23 lb_m
[f] LO_2 flow rate at MECO command - 109% RPL assessment tag value lb_m/sec
[g] Total LO_2 shutdown flow - 842.40 lb_m

TABLE 5.5 (DELETED)

TABLE 5.5.1

STANDARD MPS ASSESSMENT TAGS, BLOCK II/IIA SSMEs

TEST STAND DERIVED AVERAGE ENGINE CHARACTERISTICS

(Use these values for feasibility studies and planning)

ENGINE NO.: MS031-01H
CONTROLLER MR: 6.0320
DATE: January 31, 2001

100%		
LO_2 FLOW RATE	(lb_m/sec)	895.10
LH_2 FLOW RATE	(lb_m/sec)	148.16
GO_2 FLOW RATE	(lb_m/sec)	1.84
GH_2 FLOW RATE	(lb_m/sec)	0.66
THRUST	(lb_f)	471,095
CONTROLLER PC	(psia)	2,747.0
M/R	(MRU)	6.0414
Isp	(sec)	452.65
NOZ. EXIT AREA	(in^2)	6,507.5
GH_2 Pressurant Temp	(°R)	490
GH_2 Pressurant Press	(psia)	3,088
GO_2 Pressurant Temp	(°R)	856
GO_2 Pressurant Press	(psia)	3,294

104.5%		
LO_2 FLOW RATE	(lb_m/sec)	935.55
LH_2 FLOW RATE	(lb_m/sec)	154.87
GO_2 FLOW RATE	(lb_m/sec)	1.91
GH_2 FLOW RATE	(lb_m/sec)	0.69
THRUST	(lb_f)	492,488
CONTROLLER PC	(psia)	2.870.6
M/R	(MRU)	6.0410
Isp	(sec)	452.74
NOZ. EXIT AREA	(in^2)	6,507.8
GH_2 Pressurant Temp	(°R)	486
GH_2 Pressurant Press	(psia)	3,218
GO_2 Pressurant Temp	(°R)	871
GO_2 Pressurant Press	(psia)	3,459

TABLE 5.5.1

STANDARD MPS ASSESSMENT TAGS, BLOCK II/IIA SSMEs - Concluded

TEST STAND DERIVED AVERAGE ENGINE CHARACTERISTICS

(Use these values for feasibility studies and planning)

ENGINE NO.: MS031-01H
CONTROLLER MR: 6.0320
DATE: January 31, 2001

106%

LO_2 FLOW RATE	(lb_m/sec)	949.03
LH_2 FLOW RATE	(lb_m/sec)	157.10
GO_2 FLOW RATE	(lb_m/sec)	1.94
GH_2 FLOW RATE	(lb_m/sec)	0.70
THRUST	(lb_f)	499,625
CONTROLLER PC	(psia)	2,911.8
M/R	(MRU)	6.0408
Isp	(sec)	452.77
NOZ. EXIT AREA	(in^2)	6,507.9
GH_2 Pressurant Temp	(°R)	486
GH_2 Pressurant Press	(psia)	3,282
GO_2 Pressurant Temp	(°R)	881
GO_2 Pressurant Press	(psia)	3,544

TABLE 5.5.2 (DELETED)

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TABLE 5.5.20 (DELETED)

TABLE 5.5.21 (DELETED)

TABLE 5.5.22 (DELETED)

TABLE 5.5.23 (DELETED)

TABLE 5.5.24 (DELETED)

TABLE 5.5.25 (DELETED)

TABLE 5.5.26 (DELETED)

TABLE 5.5.27 (DELETED)

TABLE 5.5.28 (DELETED)

TABLE 5.6

ORBITAL MANEUVERING SYSTEM PERFORMANCE DATA

OME/RCS Thruster Firing	Feed From Tank	Operational Mode	OMS Flow (lb/sec)		RCS Flow (lb/sec)		Total (lb/sec)		Combined Total	Thrust (lb)			OMS Ullage Pressure[6] (psia)	
			Oxygen	Fuel	Oxygen	Fuel	Oxygen	Fuel		OMS	RCS	Total	Oxygen	Fuel
OME	Same pod	Normal	12.03	7.29			12.03	7.29	19.32	6,087		6,087	252.6	253.0
OME	Opposite pod	Crossfeed	11.62	7.16			11.62	7.16	18.78	5,896		5,896	252.7	253.1
OME	Same pod oxygen	Mixed	12.10	7.10			12.10	7.10	19.20	6,060		6,060	253.3	254.3
	Opposite pod fuel	Crossfeed												
	Opposite pod oxygen	Mixed	11.59	7.38			11.59	7.38	18.97	5,951		5,951	253.4	254.2
	Same pod fuel	Crossfeed												
Both engines[2,3]	Left hand and right hand	Pre-MECO abort	25.88	15.49			25.88	15.49	41.37	13,070		13,070	275.0	275.0
Both engines plus 18 RCS[2]	Left hand and right hand	Pre-MECO abort	22.50	13.97	31.05	20.68	53.55	34.65	88.20	11,459	14,562[5]	26,021[5]	245.0	246.3
Both engines plus 24 RCS[2]	Left hand and right hand	Pre-MECO abort	21.81	13.67	38.77	26.52	60.58	40.19	100.77	11,132	18,405[3]	29,537[5]	242.6	243.9
4 RCS	Left hand and right hand	Deorbit			8.00	4.97	8.00	4.97	12.97		3,628	3,628	255.0	255.1

TABLE 5.6

ORBITAL MANEUVERING SYSTEM PERFORMANCE DATA - Concluded

OME/RCS Thruster Firing	Feed From Tank	Operational Mode	OMS Flow (lb/sec)		RCS Flow (lb/sec)		Total (lb/sec)		Combined Total	Thrust (lb)			OMS Ullage Pressure[6] (psia)	
			Oxygen	Fuel	Oxygen	Fuel	Oxygen	Fuel		OMS	RCS	Total	Oxygen	Fuel
OME[2,4]	Same pod	Pre-MECO abort	12.23	7.33			12.23	7.33	19.56	6,171		6,171	252.5	253.0
Both OME	One pod	Dual engine Feed	22.40	14.03			22.40	14.03	36.43	11,438		11,438	247.7	248.9

NOTES:

[1] All data are at nominal steady-state conditions (except as noted below) for a single or pair of “class” engines (1.65 MR. 6,000-lb thrust).

[2] All abort cases (pre-MECO and RTLS) assume:

(a) g-level of 1.25 with the OMS tanks half full

(b) “A” leg crossfeed valves closed

[3] Assumes ullage pressure of 275 psia (for first 4.5 seconds of abort dump burn).

[4] Assumes nominal ullage pressure.

[5] Sum of absolute values of individual thrust-vectors, not total thrust vector magnitude.

[6] Tanks supplying propellant during burn.

TABLE 5.7

PRIMARY RCS THRUSTER NOMINAL STEADY-STATE THRUST CORRECTION FACTOR AND PROPELLANT FLOW AS A FUNCTION OF NUMBER OF THRUSTERS OPERATING

Number of thrusters operating	Correction factor[a] thrust/thruster C/N			Propellant flow per thruster, W lb/sec		
	Forward	Aft[b]	Aft[c]	Forward	Aft[b]	Aft[c]
1	1.009	1.009	1.032	3.14	3.14	3.21
2	1.000	1.000	1.023	3.11	3.11	3.18
3	0.992	0.990	1.012	3.08	3.08	3.14
4	0.983	0.981	1.002	3.05	3.05	3.11
5	0.974	0.971	0.993	3.03	3.02	3.09
6	N/A	0.963	0.983	N/A	2.99	3.05
7	N/A	0.952	0.971	N/A	2.96	3.02
Pre-MECO aborts						
12[d,e,f]	N/A	N/A	0.871	N/A	N/A	2.71
9[d,e,g]	N/A	N/A	0.917	N/A	N/A	2.86
Deorbit						
2[d,h]	N/A	N/A	1.039	N/A	N/A	3.24

[a] Forward thrusters

Total thrust per thruster = $CN \times F_r$

[b] Aft thrusters fed from RCS propellant tanks

Total thrust per thruster = $CN \times C_a \times F_r$

[c] Aft thrusters fed via interconnect from OMS propellant tanks

- OMS tank pressure regulated
  Total thrust per thruster - $CN \times F_r$
- OMS tank pressure decaying (blowdown mode)
  Total thrust per thruster - $CN \times F_r + 2.25\ (P_{to} - 225.0)$
  Propellant flow per thruster - Total thrust per thruster $\times$ $W/(CN \times F_r)$
  P_{to} - OMS tank pressure

See Figure 5-23 for C_a, Figure 5-24 for F_r

[d] Thrusters per pod

[e] Under boost “g” field of 1.0 to 1.5 g’s

[f] RTLS and TAL aborts

[g] AOA, ATO

[h] Aft thrusters fed from OMS propellant tanks at regulated pressure

TABLE 5.8

VERNIER THRUSTER NOMINAL STEADY-STATE THRUST CORRECTION FACTOR AND PROPELLANT FLOW AS A FUNCTION OF NUMBER OF THRUSTERS OPERATING

Number of thrusters operating	Correction factor thrust/thrusters C/N forward or aft[a]	Propellant flow per thruster W lb/sec forward or aft[b]
1	1.00	0.0923
2	0.99	0.0914

[a] For total thrust per thrusters, see equations on Table 5.7

[b] Based on one or two thruster firing with an inlet pressure of 246 psia and a propellant temperature of 70°F

TABLE 5.9

NOMINAL RCS THRUST COMPONENTS AND APPLICATION LOCATIONS

Thruster Number	Thrust Components (lb[a,c])			Resultant[c] Thrust (lb)	Thrust Application[b]		
	FX_B	FY_B	FZ_B		X_0	Y_0	Z_0
F2F	−879.4	−26.2	119.9	887.9	306.72	14.65	392.96
F3F	−879.5	0.0	122.7	888.0	306.72	0.0	394.45
F1F	−879.4	26.2	119.9	887.9	306.72	−14.65	392.96
F1L	−26.3	873.6	18.2	874.2	362.67	−69.50	373.73
F3L	−21.0	870.3	0.5	870.6	364.71	−71.65	359.25
F2R	−26.3	−873.6	18.2	874.2	362.67	69.50	373.73
F4R	−21.0	−870.3	0.5	870.6	364.71	71.65	359.25
F2U	−32.3	−11.7	874.4	875.1	350.93	14.39	413.46
F3U	−31.9	0.0	873.5	874.1	350.92	0.0	414.53
F1U	−32.3	11.7	874.4	875.1	350.93	−14.39	413.46
F2D	−28.0	−616.4	−639.5	888.6	333.84	61.42	356.95
F1D	−28.0	616.4	−639.5	888.6	333.84	−61.42	356.95
F4D	−24.8	−612.6	−639.4	885.9	348.44	66.23	358.44
F3D	−24.8	612.6	−639.4	885.9	348.44	−66.23	358.44
F5R	−0.8	−17.0	−17.6	24.5	324.35	59.70	350.12
F5L	−0.8	17.0	−17.6	24.5	324.35	−59.70	350.12
R3A	856.8	0.0	151.1	870.0	1,555.29	137.00	473.06
R1A	856.8	0.0	151.1	870.0	1,555.29	124.00	473.06
L3A	856.8	0.0	151.1	870.0	1,555.29	−137.00	473.06
L1A	856.8	0.0	151.1	870.0	1,555.29	−124.00	473.06
L4L	0.0	870.5	−22.4	870.8	1,516.00	−149.87	459.00
L2L	0.0	870.5	−22.4	870.8	1,529.00	−149.87	459.00
L3L	0.0	870.5	−22.4	870.8	1,542.00	−149.87	459.00
L1L	0.0	870.5	−22.4	870.8	1,555.00	−149.87	459.00
R4R	0.0	−870.5	−22.4	870.8	1,516.00	149.87	459.00
R2R	0.0	−870.5	−22.4	870.8	1,529.00	149.87	459.00
R3R	0.0	−870.5	−22.4	870.8	1,542.00	149.87	459.00
R1R	0.0	−870.5	−22.4	870.8	1,555.00	149.87	459.00
L4U	0.0	0.0	870.0	870.0	1,516.00	−132.00	480.50

TABLE 5.9

NOMINAL RCS THRUST COMPONENTS AND APPLICATION LOCATIONS - Concluded

Thruster Number	Thrust Components (lb[a,c])			Resultant[c] Thrust (lb)	Thrust Application[b]		
	FX_B	FY_B	FZ_B		X_0	Y_0	Z_0
L2U	0.0	0.0	870.0	870.0	1,529.00	−132.00	480.50
L1U	0.0	0.0	870.0	870.0	1,542.00	−132.00	480.50
R4U	0.0	0.0	870.0	870.0	1,516.00	132.00	480.50
R2U	0.0	0.0	870.0	870.0	1,529.00	132.00	480.50
R1U	0.0	0.0	870.0	870.0	1,542.00	132.00	480.50
L4D	170.4	291.8	−801.7	870.0	1,516.00	−111.95	437.40
L2D	170.4	291.8	−801.7	870.0	1,529.00	−111.00	440.00
L3D	170.4	291.8	−801.7	870.0	1,542.00	−110.06	442.60
R4D	170.4	−291.8	−801.7	870.0	1,516.00	111.95	437.40
R2D	170.4	−291.8	−801.7	870.0	1,529.00	111.00	440.00
R3D	170.4	−291.8	−801.7	870.0	1,542.00	110.06	442.60
L5D	0.0	0.0	−24.0[d]	24.0[d]	1,565.00	−118.00	455.44
R5D	0.0	0.0	−24.0[d]	24.0[d]	1,565.00	118.00	455.44
L5L	0.0	24.0	−0.6	24.0	1,565.00	−149.87	459.00
R5R	0.0	−24.0	−0.6	24.0	1,565.00	149.87	459.00

[a] Motion coordinates - Figure 3-22

[b] Station coordinates - Figure 3-22

[c] For impingement effects above 475,000 feet, refer to Aerodynamic Design Data Book, Volume I SD 72-SH-0060-IL-7, Appendix C

[d] For impingement effects, refer to EX32/8202-24

TABLE 5.10

MR AND SPECIFIC IMPULSE (Isp) FOR VARIOUS RCS USAGE MODES

RCS Usage Mode	Expected MR	Effective Isp
RCS deorbit:		
4 + X thrusters	1.581	283.6
3 + X thrusters OMS propellant	1.587	283.3
2 + X thrusters	1.592	283.0
−X translation maneuver:	1.602	287.8

NOTE: Isp based on average acceptance-test thruster performance.

TABLE 5.11

PROPELLANT CHARACTERISTICS

Formulation	Percent by Weight	Molecular Weight	Enthalpy At 298.1°K, (cal/mole)	Density (gm/cc)
Ammonium perchlorate	69.6	177.5	−70,590	1.95
Aluminum	16.0	26.981	0	2.699
Iron oxide	0.4	159.7	−197,300	5.120
PBAN polymer	12.04	100.0[a]	−12,000	0.931
Epoxy curing agent	1.96	100.0[a]	−28,300	1.129

Physical Properties (JANNAF Uniaxial)	Temperature		
	0	77	90
Initial modulus (psi)	5,953	646	502
Strain at maximum stress (percent)	33	44	43
Tensile strength (psi)	379	103	92

Ballistic Properties (P_c = 1,000 psia, 60°F)	Chamber	Nozzle	Exit
Flame temperature (°F)	5,718	5,351	3,383
Molecular weight (lb/lb−mole)	28.48	28.69	29.33
Specific heat ratio	1.142	1.144	1.184
Blowing coefficient, corrosivity index	0.1072	0.1059	0.1038
Characteristic velocity (fps)			5,155
Density (lb/in^3)			0.06347

Burning rate a 1,000 psia (nominal and limits [in/sec])	
40°F	0.428 ± 0.020
60°F	0.431 ± 0.020
90°F	0.443 ± 0.022
Burning rate coefficient	0.386625
Burning rate exponent	0.35
Effective nozzle specific heat ratio	1.145
Vacuum theoretical specific impulse (lb/sec/lb)	276.2
Expansion ratio	7.72
Absolute viscosity of chamber gas (lb_f/sec/in/ft)	1.62×10^{-7}

[a] Average molecular weight of polymer and epoxy curing agent are 3,300 and 360. Values shown in table are consistent with heat of formation data.

TABLE 5.12

SRB NOZZLE CHARACTERISTICS

Parameter	RSRM
Nozzle type	Contoured
Expansion ratio	7.72:1
Initial exit diameter (in)	149.644
Final predicted exit diameter (in)	149.954
Initial throat diameter (in)	53.858
Final throat diameter (in)	55.950
Nozzle extension jettisonable	Yes
Nozzle length throat-to-exit (in)	154.195
Nozzle total length (in)	177.7
Submergence ratio	0.226
Initial L/RT	5.28
Exit cone, contoured	
Initial angle (deg)	24.6
Turnback angle (deg)	14.14
Exit angle (deg)	10.46
Nozzle null position-pitch-WRT centerline (deg)	0.0
Tolerance on null position-pitch (deg)	1.0
Nozzle null position-yaw-away from actuators WRT centerline (deg)	*
Tolerance on null position-yaw (deg)	0.5

*Shifts accordingly with the increase in motor pressure.

TABLE 5.13

SRB ± 3-SIGMA TOLERANCE REQUIREMENTS

Parameter	SVB Population %	Max. Diff. Between Paired SRBs %
Web Time	± 4.9*	2.0
Action Time	–	3.0
Web Time Average Vac Thrust	± 5.2* (5.3)	–
Vac Delivered Specified Impulse	± 0.5	1.0
Propellant Weight	± 0.21	–
SRB Inert Weight Prelaunch	+ 0.85	–

* Does not include uncertainty in temperature prediction or development tolerance.

– The ± 3σ web action time tolerance including uncertainty in temperature prediction and development tolerance is given by

$$\Delta \text{ WAT} = \pm \left[\left(\text{FLT}/\text{FLT}_{\text{TOL}}\right)^2 + \left(\text{DEVELOP}_{\text{TOL}}\right)^2 + (\text{TEMP. UNC.})^2 \right]^{\frac{1}{2}}$$

Where $\text{FLT/FLT}_{\text{TOL}}$ = 4.9% before 5 inch C.P. tests

= 3.7% after 5 inch C.P. tests

$\text{Develop}_{\text{TOL}}$ = 3.0%

Temp. Unc. = 1.3% to account for 10°F temperature uncertainty

( ) Total SRB Population %

TABLE 5.14

RSRM PREDICTED PMBT BASED ON 33-YEAR MEAN OF 30-DAY AVERAGE

	AVG	+ 3 SIGMA	− 3 SIGMA
JAN			
01-03	64	73	54
04-12	63	73	53
13-24	62	73	51
25-31	61	73	50
FEB			
01-22	61	73	50
23-28	62	72	52
MAR			
01-04	62	72	52
05-12	63	72	53
13-19	64	73	55
20-26	65	73	56
27-31	66	74	58
APR			
01-02	66	74	58
03-08	67	74	60
09-14	68	75	61
15-21	69	75	63
22-27	70	76	65
28-30	71	76	66
MAY			
01-03	71	76	66
04-10	72	77	68
11-16	73	77	69
17-23	74	78	70
24-30	75	79	71
31	76	80	72
JUN			
01-05	76	80	72
06-12	77	81	73
13-21	78	82	74
22-30	79	83	76

	AVG	+ 3 SIGMA	− 3 SIGMA
JUL			
01	79	83	76
02-16	80	84	77
17-31	81	84	78
AUG			
01-15	81	84	78
16-31	82	84	79
SEP			
01	82	84	79
02-29	81	84	78
30	80	83	77
OCT			
01-08	80	83	77
09-15	79	83	75
16-20	78	82	74
21-25	77	81	73
26-30	76	81	71
31	75	80	70
NOV			
01-04	75	80	70
05-08	74	79	69
09-13	73	79	67
14-18	72	78	66
19-23	71	78	64
24-28	70	78	62
29-30	69	77	61
DEC			
01-03	69	77	61
04-08	68	77	59
09-13	67	76	58
14-19	66	75	57
20-26	65	74	55
27-31	64	74	54

TABLE 5.15 (DELETED)

TABLE 5.16

SRB MOTOR PERFORMANCE AT ANY PMBT

$$\text{Thrust}_{PMBT} = T(\text{Baseline motor}) \times e^{\pi_K(\Delta PMBT)}$$

$$\text{Time}_{PMBT} = t(\text{Baseline motor}) \times e^{-\sigma_K(\Delta PMBT)}$$

$$\text{Isp}_{PMBT} = \text{Isp}(\text{Baseline motor}) \times e^{(\pi_K - \sigma_K)\,\Delta PMBT}$$

$$\text{Burn Rate}_{PMBT} = RB(\text{Baseline or Launch motor}) \times e^{\sigma_P(\Delta PMBT)}$$

Where $\pi_K = 0.0011$

$\sigma_K = 0.001063$

$\sigma_P = 0.0006783$

$\Delta PMBT = PMBT_{new} - PMBT_{old}$

TABLE 5.17 (RESERVED)

TABLE 5.18

PREDICTED PERFORMANCE TIME HISTORY (60°F) FOR RSRM (TP-R074-99)

Time (Sec)	Vacuum Thrust (lb_f)	Total Flowrate (lb_m/Sec)	Vacuum Isp (Sec)
0.0	258363.0	0.000	1.000
0.2	1512482.5	6991.335	216.337
0.4	2956528.8	10914.107	270.891
0.6	3135198.7	11663.259	268.810
0.8	3139373.4	11677.258	268.845
1.0	3142301.7	11677.458	269.091
2.0	3138625.0	11663.759	269.092
3.0	3145087.1	11687.658	269.095
4.0	3162998.7	11754.054	269.099
5.0	3192823.3	11864.447	269.108
6.0	3226319.9	11988.539	269.117
7.0	3247308.7	12066.934	269.108
8.0	3260390.5	12116.131	269.095
9.0	3272961.0	12163.528	269.080
10.0	3283089.9	12201.825	269.065
11.0	3287473.6	12218.924	269.048
12.0	3289069.4	12225.624	269.031
13.0	3291665.1	12236.023	269.014
14.0	3295425.0	12250.722	268.998
15.0	3299545.6	12266.821	268.981
16.0	3304423.7	12285.820	268.962
17.0	3310524.1	12309.518	268.940
18.0	3316704.8	12333.617	268.916
19.0	3321234.9	12351.816	268.886
20.0	3324275.7	12364.615	268.854
21.0	3326310.9	12373.714	268.821
22.0	3312237.8	12323.617	268.772
23.0	3258824.2	12129.630	268.666
24.0	3198191.0	11908.844	268.556
25.0	3143999.8	11711.656	268.450
26.0	3096414.0	11538.767	268.349

TABLE 5.18

PREDICTED PERFORMANCE TIME HISTORY (60°F) FOR RSRM (TP-R074-99) - Continued

Time (Sec)	Vacuum Thrust (lb_f)	Total Flowrate (lb_m/Sec)	Vacuum Isp (Sec)
27.0	3053672.7	11383.777	268.248
28.0	3014286.6	11240.886	268.154
29.0	2977190.9	11106.295	268.063
30.0	2941672.3	10977.303	267.978
31.0	2907296.3	10852.411	267.894
32.0	2873832.9	10730.719	267.814
33.0	2841183.4	10612.126	267.730
34.0	2809309.7	10496.333	267.647
35.0	2778184.1	10383.141	267.567
36.0	2747765.0	10272.448	267.489
37.0	2717977.0	10163.755	267.419
38.0	2688691.4	10056.961	267.346
39.0	2659765.2	9951.768	267.266
40.0	2631292.8	9848.575	267.175
41.0	2603916.2	9749.481	267.083
42.0	2578589.2	9657.387	267.007
43.0	2555759.9	9574.392	266.937
44.0	2535100.1	9500.397	266.841
45.0	2516015.8	9433.001	266.725
46.0	2498155.4	9369.105	266.638
47.0	2478778.1	9298.709	266.572
48.0	2451099.3	9200.216	266.418
49.0	2417847.2	9079.623	266.294
50.0	2390874.2	8981.130	266.211
51.0	2375504.6	8928.033	266.073
52.0	2366448.7	8896.935	265.985
53.0	2365639.1	8895.135	265.948
54.0	2373535.1	8926.233	265.906
55.0	2385813.5	8972.930	265.890
56.0	2399183.4	9023.427	265.884
57.0	2412409.4	9073.224	265.882

TABLE 5.18

PREDICTED PERFORMANCE TIME HISTORY (60°F) FOR RSRM (TP-R074-99) - Continued

Time (Sec)	Vacuum Thrust (lb_f)	Total Flowrate (lb_m/Sec)	Vacuum Isp (Sec)
58.0	2425284.0	9121.721	265.880
59.0	2437776.6	9168.618	265.883
60.0	2449821.5	9213.515	265.894
61.0	2461355.9	9256.312	265.911
62.0	2472367.2	9297.210	265.926
63.0	2482939.6	9336.507	265.939
64.0	2493295.8	9375.205	265.946
65.0	2503746.0	9414.402	265.948
66.0	2514482.4	9454.700	265.951
67.0	2525338.3	9495.097	265.962
68.0	2535923.3	9535.394	265.948
69.0	2546755.7	9576.292	265.944
70.0	2555903.1	9610.390	265.952
71.0	2562632.8	9636.388	265.933
72.0	2568354.9	9657.787	265.936
73.0	2573399.8	9676.486	265.944
74.0	2577542.9	9692.285	265.938
75.0	2580614.6	9704.284	265.925
76.0	2582675.8	9711.383	265.943
77.0	2583428.9	9714.283	265.941
78.0	2581143.7	9707.384	265.895
79.0	2570222.8	9664.786	265.937
80.0	2542440.5	9565.093	265.804
81.0	2513434.1	9455.400	265.820
82.0	2491651.1	9378.304	265.682
83.0	2466517.4	9286.410	265.605
84.0	2434013.5	9163.418	265.623
85.0	2403005.3	9052.125	265.463
86.0	2376476.0	8951.732	265.477
87.0	2343437.9	8827.339	265.475
88.0	2300098.3	8667.050	265.384

TABLE 5.18

PREDICTED PERFORMANCE TIME HISTORY (60°F) FOR RSRM (TP-R074-99) - Continued

Time (Sec)	Vacuum Thrust (lb_f)	Total Flowrate (lb_m/Sec)	Vacuum Isp (Sec)
89.0	2255686.7	8500.260	265.367
90.0	2223152.0	8377.868	265.360
91.0	2206580.6	8317.472	265.295
92.0	2196601.5	8280.274	265.281
93.0	2181407.6	8224.278	265.240
94.0	2159427.4	8144.183	265.150
95.0	2131863.6	8042.089	265.088
96.0	2099677.1	7923.597	264.990
97.0	2069227.8	7811.104	264.908
98.0	2043237.6	7715.710	264.815
99.0	2019687.2	7627.716	264.783
100.0	1997019.0	7546.021	264.645
101.0	1970582.6	7448.127	264.574
102.0	1937714.4	7326.135	264.493
103.0	1900434.8	7162.745	265.322
104.0	1862123.0	6985.856	266.556
105.0	1823659.3	6807.668	267.883
106.0	1784354.0	6628.179	269.207
107.0	1749973.0	6477.389	270.166
108.0	1730509.0	6405.593	270.156
109.0	1715108.1	6350.397	270.079
110.0	1673941.5	6196.706	270.134
111.0	1586122.2	5874.627	269.995
112.0	1460295.1	5420.656	269.395
113.0	1266421.3	4707.801	269.005
114.0	1019896.6	3789.959	269.105
115.0	823344.8	3054.006	269.595
116.0	688472.1	2552.638	269.710
117.0	573705.1	2128.265	269.565
118.0	469343.4	1741.789	269.461
119.0	377113.0	1402.011	268.980

TABLE 5.18

PREDICTED PERFORMANCE TIME HISTORY (60°F) FOR RSRM (TP-R074-99) - Concluded

Time (Sec)	Vacuum Thrust (lb_f)	Total Flowrate (lb_m/Sec)	Vacuum Isp (Sec)
120.0	285006.5	1060.433	268.764
121.0	204454.7	763.966	267.623
122.0	147180.3	555.865	264.777
123.0	105917.9	410.774	257.850
124.0	75463.2	301.681	250.142
125.0	53569.7	219.886	243.625
126.0	37051.1	155.190	238.747
127.0	25762.2	100.894	255.339
128.0	14170.1	63.696	222.465
129.0	9240.6	51.897	178.057

TABLE 5.19

RSRM NOMINAL THRUST-TIME LIMITS (VACUUM - 60°F) (TP-R074-99)

Time (Sec)	Minimum (Klb)	Nominal (Klb)	Maximum (Klb)
1	3048.0	3142.3	3236.6
2	3044.5	3138.6	3232.8
3	3050.7	3145.1	3239.4
4	3068.1	3163.0	3257.9
5	3097.0	3192.8	3288.6
6	3129.5	3226.3	3323.1
7	3149.9	3247.3	3344.7
8	3162.6	3260.4	3358.2
9	3174.8	3273.0	3371.1
10	3184.6	3283.1	3381.6
11	3188.8	3287.5	3386.1
12	3190.4	3289.1	3387.7
13	3192.9	3291.7	3390.4
14	3196.6	3295.4	3394.3
15	3200.6	3299.5	3398.5
16	3205.3	3304.4	3403.6
17	3211.2	3310.5	3409.8
18	3217.2	3316.7	3416.2
19	3221.6	3321.2	3420.9
20	3224.5	3324.3	3424.0
21	3226.5	3326.3	3426.1
22	3212.9	3312.2	3411.6
23	3161.1	3258.8	3356.6
24	3102.2	3198.2	3294.1
25	3049.7	3144.0	3238.3
26	3003.5	3096.4	3189.3
27	2962.1	3053.7	3145.3
28	2923.9	3014.3	3104.7
29	2887.9	2977.2	3066.5
30	2853.4	2941.7	3029.9
31	2820.1	2907.3	2994.5
32	2787.6	2873.8	2960.0

TABLE 5.19

RSRM NOMINAL THRUST-TIME LIMITS (VACUUM - 60°F) (TP-R074-99) - Continued

Time (Sec)	Minimum (Klb)	Nominal (Klb)	Maximum (Klb)
33	2755.9	2841.2	2926.4
34	2725.0	2809.3	2893.6
35	2694.8	2778.2	2861.5
36	2665.3	2747.8	2830.2
37	2636.4	2718.0	2799.5
38	2608.0	2688.7	2769.4
39	2580.0	2659.8	2739.6
40	2552.4	2631.3	2710.2
41	2525.8	2603.9	2682.0
42	2501.2	2578.6	2655.9
43	2479.1	2555.8	2632.4
44	2459.0	2535.1	2611.2
45	2440.5	2516.0	2591.5
46	2423.2	2498.2	2573.1
47	2404.4	2478.8	2553.1
48	2377.6	2451.1	2524.6
49	2345.3	2417.8	2490.4
50	2319.1	2390.9	2462.6
51	2304.2	2375.5	2446.8
52	2295.5	2366.4	2437.4
53	2294.7	2365.6	2436.6
54	2302.3	2373.5	2444.7
55	2314.2	2385.8	2457.4
56	2327.2	2399.2	2471.2
57	2340.0	2412.4	2484.8
58	2352.5	2425.3	2498.0
59	2364.6	2437.8	2510.9
60	2376.3	2449.8	2523.3
61	2387.5	2461.4	2535.2
62	2398.2	2472.4	2546.5
63	2408.5	2482.9	2557.4
64	2418.5	2493.3	2568.1

TABLE 5.19

RSRM NOMINAL THRUST-TIME LIMITS (VACUUM - 60°F) (TP-R074-99) - Continued

Time (Sec)	Minimum (Klb)	Nominal (Klb)	Maximum (Klb)
65	2428.6	2503.7	2578.9
66	2439.0	2514.5	2589.9
67	2449.6	2525.3	2601.1
68	2459.8	2535.9	2612.0
69	2470.4	2546.8	2623.2
70	2479.2	2555.9	2632.6
71	2485.8	2562.6	2639.5
72	2491.3	2568.4	2645.4
73	2496.2	2573.4	2650.6
74	2500.2	2577.5	2654.9
75	2503.2	2580.6	2658.0
76	2505.2	2582.7	2660.2
77	2505.9	2583.4	2660.9
78	2503.7	2581.1	2658.6
79	2493.1	2570.2	2647.3
80	2466.2	2542.4	2618.7
81	2438.0	2513.4	2588.8
82	2416.9	2491.7	2566.4
83	2392.5	2466.5	2540.5
84	2361.0	2434.0	2507.0
85	2330.9	2403.0	2475.1
86	2305.2	2376.5	2447.8
87	2273.1	2343.4	2413.7
88	2231.1	2300.1	2369.1
89	2188.0	2255.7	2323.4
90	2156.5	2223.2	2289.8
91	2140.4	2206.6	2272.8
92	2130.7	2196.6	2262.5
93	2116.0	2181.4	2246.8
94	2094.6	2159.4	2224.2
95	2067.9	2131.9	2195.8
96	2036.7	2099.7	2162.7

TABLE 5.19

RSRM NOMINAL THRUST-TIME LIMITS (VACUUM - 60°F) (TP-R074-99) - Concluded

Time (Sec)	Minimum (Klb)	Nominal (Klb)	Maximum (Klb)
97	2007.2	2069.2	2131.3
98	1981.9	2043.2	2104.5
99	1959.1	2019.7	2080.3
100	1937.1	1997.0	2056.9
101	1911.5	1970.6	2029.7
102	1879.6	1937.7	1995.8
103	1843.4	1900.4	1957.4
104	1806.3	1862.1	1918.0
105	1768.9	1823.7	1878.4
106	1730.8	1784.4	1837.9
107	1649.6	1750.0	1802.5
108	1546.9	1730.5	1782.4
109	1395.3	1715.1	1766.6
110	1167.4	1673.9	1756.4
111	927.2	1586.1	1734.2
112	756.4	1460.3	1719.7
113	630.6	1266.4	1689.3
114	517.2	1019.9	1617.2
115	417.3	823.3	1508.0
116	323.1	688.5	1347.0
117	232.4	573.7	1120.6
118	165.1	469.3	901.6
119	117.8	377.1	747.1
120	83.3	285.0	629.5
121	58.6	204.5	522.4
122	40.5	147.2	427.4
123	28.3	105.9	338.9
124	15.1	75.5	251.0
125	9.6	53.6	181.6
126	0.0	37.1	132.2
127	0.0	25.8	95.8
128	0.0	14.2	68.8

TABLE 5.20

RSRM BLOCK MOTOR THRUST ADJUSTMENT INCREMENTS*

% Separation Time	% Action Time	Thrust Adjustment (lbs)
0	0.0	0
1	1.017349	10000
24	24.41637	10000
37	37.6419	– 14000
39	39.6766	– 14000
43	43.74599	2000
48	48.83273	2000
53	53.91948	– 7000
67	68.16236	2500
69	70.19705	2500
77	78.33584	– 5000
81	82.40524	– 14000
87	88.50933	– 14000
89	90.54403	– 2000
90	91.56137	– 2000
94	95.63077	2000
95	96.64812	2000
96	97.66547	0
100	101.7349	0

*Applied to each motor

TABLE 5.21 (DELETED)

TABLE 5.22 (DELETED)

TABLE 5.22.1

RSRM BLOCK MOTOR PREDICTIONS PERFORMANCE SUMMARY, PMBT = 70°F

Parameter	T-Delay I-Load = 4.42 secs	
	Undegraded	Adjusted[a]
Action Time Total Impulse, Vac., 10^6 lb_f-sec	297.00	293.69
Average Specific Impulse, Vac., sec	268.52	265.53
Web Time, sec	109.93	109.93
50 psia Cue Time, sec[b]	119.75	119.75
Action Time, sec[c]	122.20	122.20
Separation Time, sec	124.32	124.32

NOTES:

[a] Reduction of performance based upon Paragraph 5.4.

[b] Separation Cue - The separation cue is defined as the time point at which the head-end chamber pressure has decayed to 50 psia. Separation events occur at T-Delay seconds after the last RSRM to reach 50 psia of head-end pressure. These events occur at an even 0.16-second cycle time.

[c] End of Action Time - The end of action time is defined as the time point at which the head-end chamber pressure has decayed to 22.1 psia.

TABLE 5.22.2 (DELETED)

TABLE 5.23 (DELETED)

TABLE 5.23.1 (DELETED)

TABLE 5.23.2

ADJUSTED RSRM BLOCK MOTOR PREDICTIONS PERFORMANCE SUMMARY, PMBT = 70°F T - DELAY I-LOAD = 4.42 SEC LIGHTWEIGHT CASE

Parameter	
Action time total impulse, Vac, 10^6 lb-sec[a]	293.69
Average specific impulse, Vac, sec[a]	265.53
Web time, sec	109.93
50 psia cue time, sec[b]	119.75
Action time, sec[c]	122.20
Separation time, sec	124.32

NOTES:

[a] Reduction of Performance based upon Paragraph 5.4.

[b] Separation cue - The separation cue is defined as the time point at which the headend chamber pressure has decayed to 50 psia. Separation event occurs at t-Delay seconds after the last RSRM to reach 50 psia of head pressure (t-Delay I-Load = 4.42). These events occur at an even 0.16 second cycle time.

[c] End of action time - The end of action time is defined as the time point at which the headend chamber pressure has decayed to 22.1 psia.

TABLE 5.24

BLOCK MOTOR PREDICTIONS
PERFORMANCE MODIFICATION EQUATIONS

$$T_A = T_N \times e^{K1} \times KW_A{}^{1.53846}$$

$$T_B = T_N \times e^{K2} \times KW_B{}^{1.53846}$$

$$P_A = P_N \times e^{K1} \times KW_A{}^{1.53846}$$

$$P_B = P_N \times e^{K2} \times KW_B{}^{1.53846}$$

$$t_A = t_N \times e^{-K3} \times KW_A{}^{-.53846}$$

$$t_B = t_N \times e^{-K4} \times KW_B{}^{-.53846}$$

$$w_A = w_N \times e^{K3} \times KW_A{}^{1.53846}$$

$$w_B = w_N \times e^{K4} \times KW_B{}^{1.53846}$$

$$Isp_A = Isp_N \times e^{K5}$$

$$Isp_B = Isp_N \times e^{K5}$$

where

$$K1 = K6\left(PM - PM_N\right) + K7\left(PMRB_A\right)$$

$$K2 = K6\left(PM - PM_N\right) + K7\left(PMRB_B\right)$$

$$K3 = K7\left(PM - PM_N + PMRB_A\right)$$

$$K4 = K7\left(PM - PM_N + PMRB_B\right)$$

$$K5 = K9\left(PM - PM_N\right)$$

$$K6 = 0.0011$$

$$K7 = 0.001063$$

$$K9 = 0.000037$$

$$K10 = 1474.274$$

$$PMRB_A = K10 \times \ln\left(\frac{RB_A}{RB_N}\right)$$

$$PMRB_B = K10 \times \ln\left(\frac{RB_B}{RB_N}\right)$$

$$KW_A = \frac{WP_A}{WP_N}$$

$$KW_B = \frac{WP_B}{WP_N}$$

TABLE 5.24

BLOCK MOTOR PREDICTIONS
PERFORMANCE MODIFICATION EQUATIONS - Continued

A = Left motor
B = Right motor
N = Baseline motor
T = Thrust
P = Chamber Pressure
t = Time
w = Weight Flow Rate
Isp = Specific Impulse
PM = Propellant Mean Bulk Temperature
RB = Propellant burn Rate
WP = Propellant Weight

$$W_A(t_{MP}) = W_N(t_{MP}) + (WP_A - WP_N) * \left[1 - \left(\frac{t_{MP}}{t_{MPSEP}}\right)\right] + (WI_A - WI_N)$$

$$W_B(t_{MP}) = W_N(t_{MP}) + (WP_B - WP_N) * \left[1 - \left(\frac{t_{MP}}{t_{MPSEP}}\right)\right] + (WI_B - WI_N)$$

When $t_{MP} < t_{MPSEP}$,

$$t_{MP_A} = t_{MP} \times e^{-K3} \times KW_A^{\ -.53846}$$

$$t_{MP_B} = t_{MP} \times e^{-K4} \times KW_B^{\ -.53846}$$

When $t_{MP} \geq t_{MPSEP}$,

$$t_{MP_A} = t_{MP} \times \left(\frac{t_{SEP}}{t_{MPSEP}}\right)$$

$$t_{MP_B} = t_{MP} \times \left(\frac{t_{SEP}}{t_{MPSEP}}\right)$$

Where t_{MP} = Mass Property Time
t_{MPSEP} = Mass Property Separation Time
W = Total SRB Weight
t_{SEP} = Nominal Separation Time
WI = Inert SRB Weight

The initial point is defined for ETR as:

P_N = 14.69 psia
T_N = 258,363.0 lbs

TABLE 5.24

BLOCK MOTOR PREDICTIONS
PERFORMANCE MODIFICATION EQUATIONS - Concluded

The nozzle erosion rate is linear over action time (head pressure of 22.1 psia) with:

Initial exit diameter = 149.644 in
Final exit diameter = 149.954 in

TABLE 5.25

RSRM MEAN TAIL-OFF THRUST AND SHAPE FACTORS

Time from Pc=50 Sec's	$F_{82\ DEG}$ Mean Thrust at 82°F 0.373 ips, lbs	$F_{50\ DEG}$ Mean Thrust at 50°F 0.363 ips, lbs	Shape Factor, lbs
0.00	204400	204400	0
0.50	172598	174506	16972
1.00	145104	148811	23224
1.50	122257	127201	26947
2.00	102603	108343	28342
2.50	85983	91752	29926
3.00	71766	77968	30664
3.50	59927	65601	31056
4.00	49444	55719	31379
4.50	41143	46747	31572
5.00	33997	39291	31435
5.50	27715	32498	30606
6.00	19623	28831	29164
6.50	14776	21510	25704
7.00	11486	15561	19137
7.50	10026	11947	14828

TABLE 5.25

RSRM MEAN TAIL-OFF THRUST AND SHAPE FACTORS - Concluded

Time from Pc=50 Sec's	$F_{82\ DEG}$ Mean Thrust at 82°F 0.373 ips, lbs	$F_{50\ DEG}$ Mean Thrust at 50°F 0.363 ips, lbs	Shape Factor lbs
8.00	8448	10020	13818
8.50	7147	8832	12683
9.00	6011	7570	12243
9.50	4762	6422	11834
10.00	3920	5521	10038
11.00	3081	3646	6561
12.00	2408	2891	6016
13.00	2024	2329	4559
14.00	1438	2147	4361
15.00	1098	1489	4168
16.00	617	1158	3847
17.00	519	783	3545
18.00	88	480	3516
19.00	39	275	3516
20.00	24	81	3516

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FIGURE 5-1

MAIN PROPULSION SUBSYSTEM

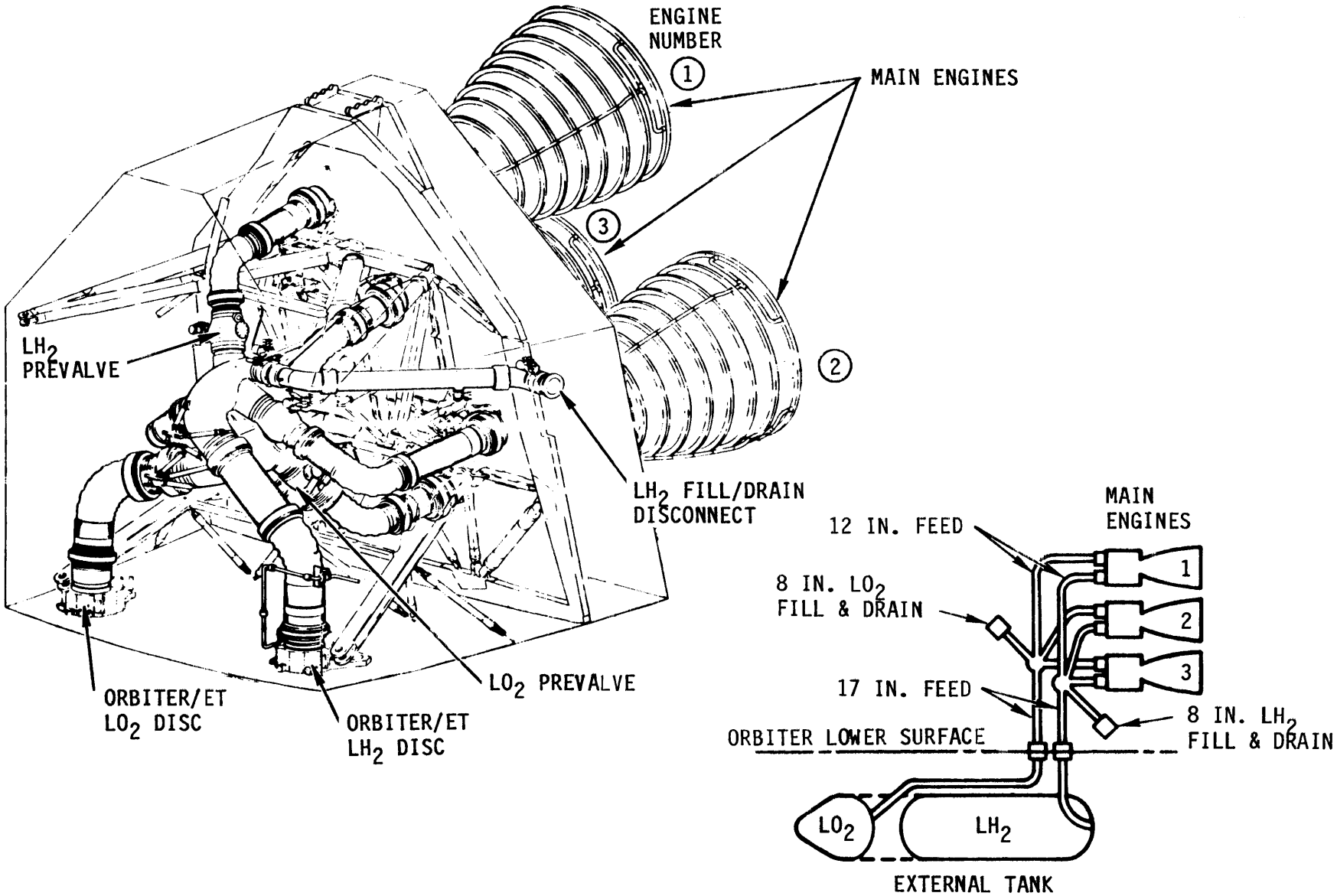


FIGURE 5-2

MAIN PROPULSION SUBSYSTEM SCHEMATIC

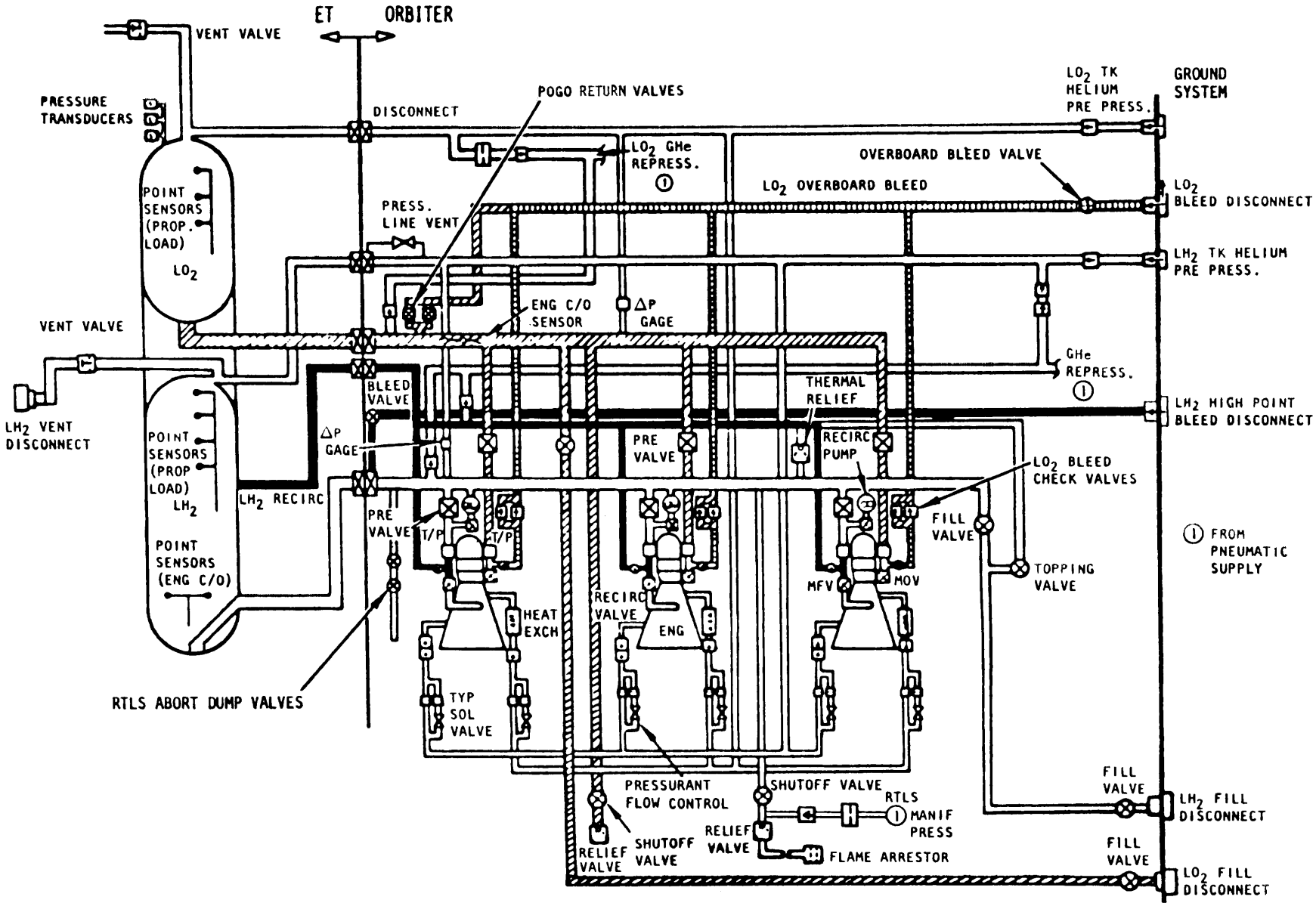
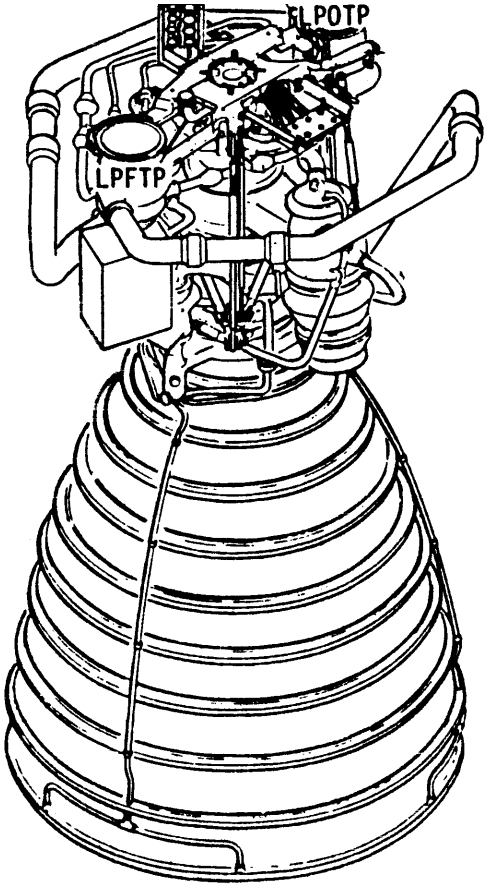


FIGURE 5-3

SPACE SHUTTLE MAIN ENGINE



RPL Thrust (lb_f)	Generic	Phase II	Block I/IA	Block IIA	Block II
Sea Level	375,000	--	--	--	--
Vacuum	470,000	--	--	--	--
Chamber Pressure (psia)	--	3,006	3,020	2,747	2,747
Throttling (% RPL)	65 to 109	--	--	--	--
MR	6.0:1	--	--	--	--
Area Ratio	--	77.5:1	77.5:1	69.2:1	69.2:1
Length (inches)	167	--	--	--	--
Diameter (inches)					
Powerhead	150 x 94.5	--	--	--	--
Nozzle Exit	94	--	--	--	--
Weight (lb_m)	--	7,029	7,380	7,482	7,748
Life					
Hours	7.5	--	--	--	--
Starts	55	--	--	--	--

FIGURE 5-4 (DELETED)

FIGURE 5-5 (DELETED)

FIGURE 5-5-1

BSM THRUST PROFILE AT 30 PMBT

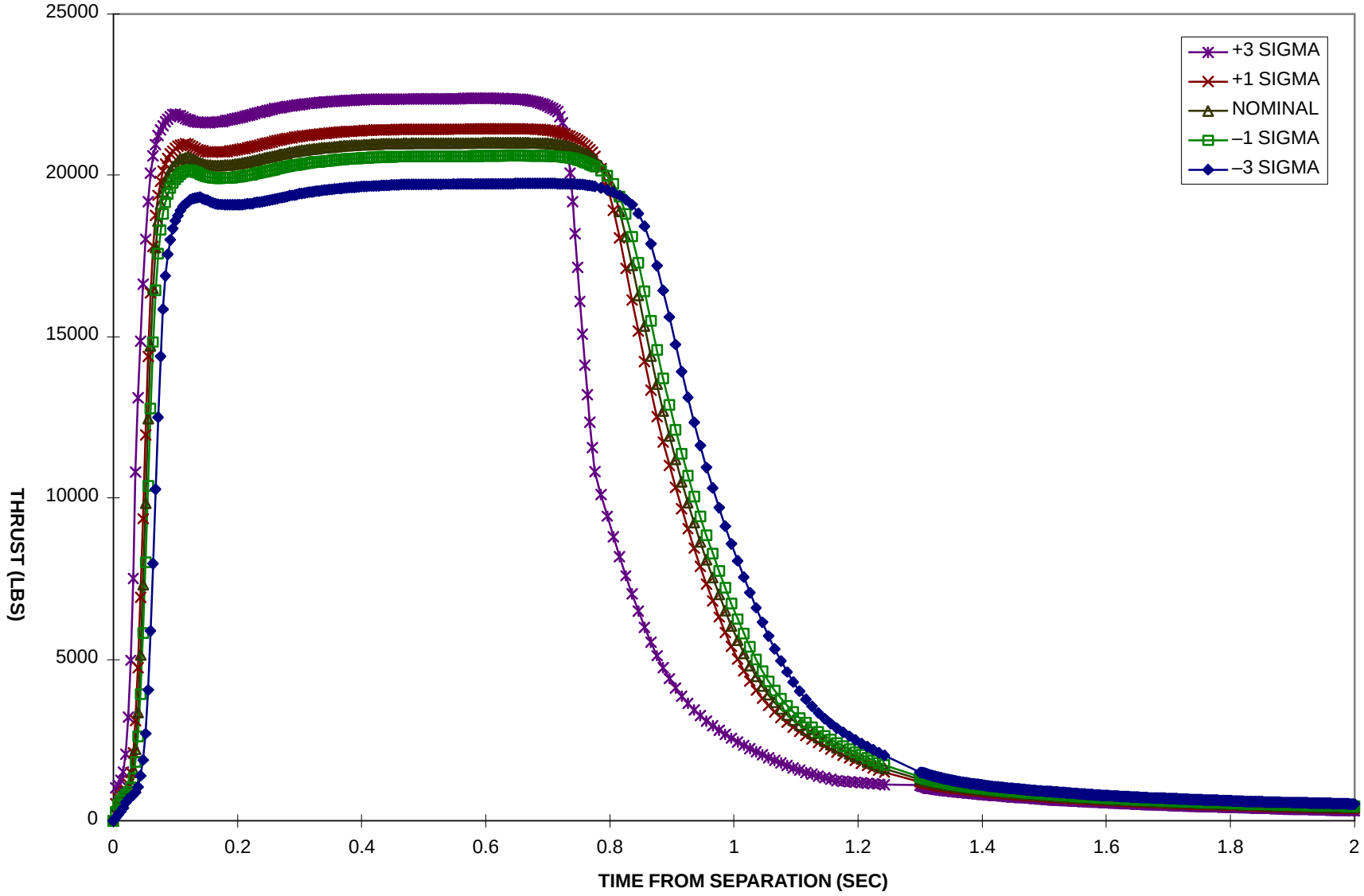


FIGURE 5-5-2

BSM THRUST PROFILE AT 70 PMBT

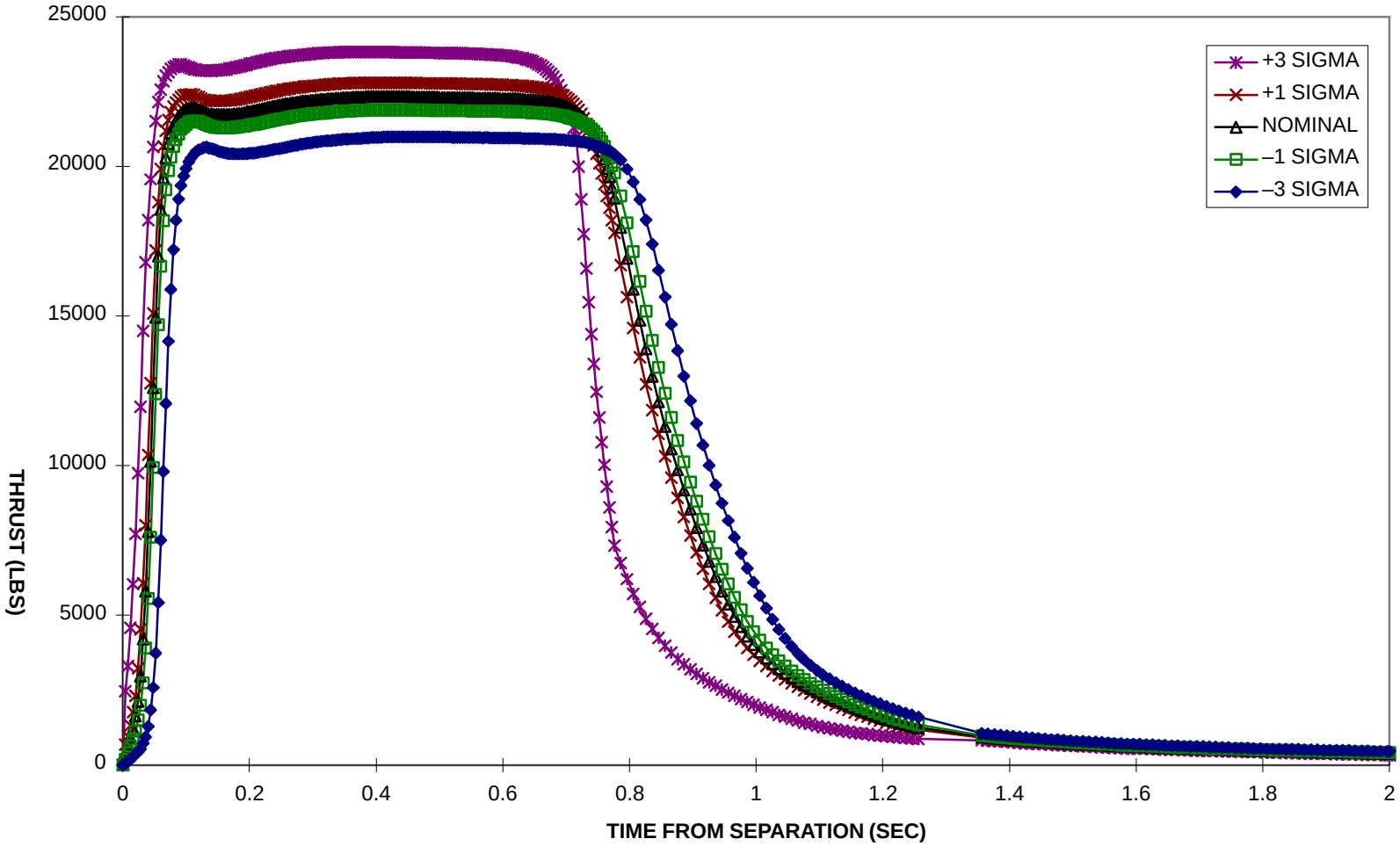


FIGURE 5-5-3

BSM THRUST PROFILE AT 100 PMBT

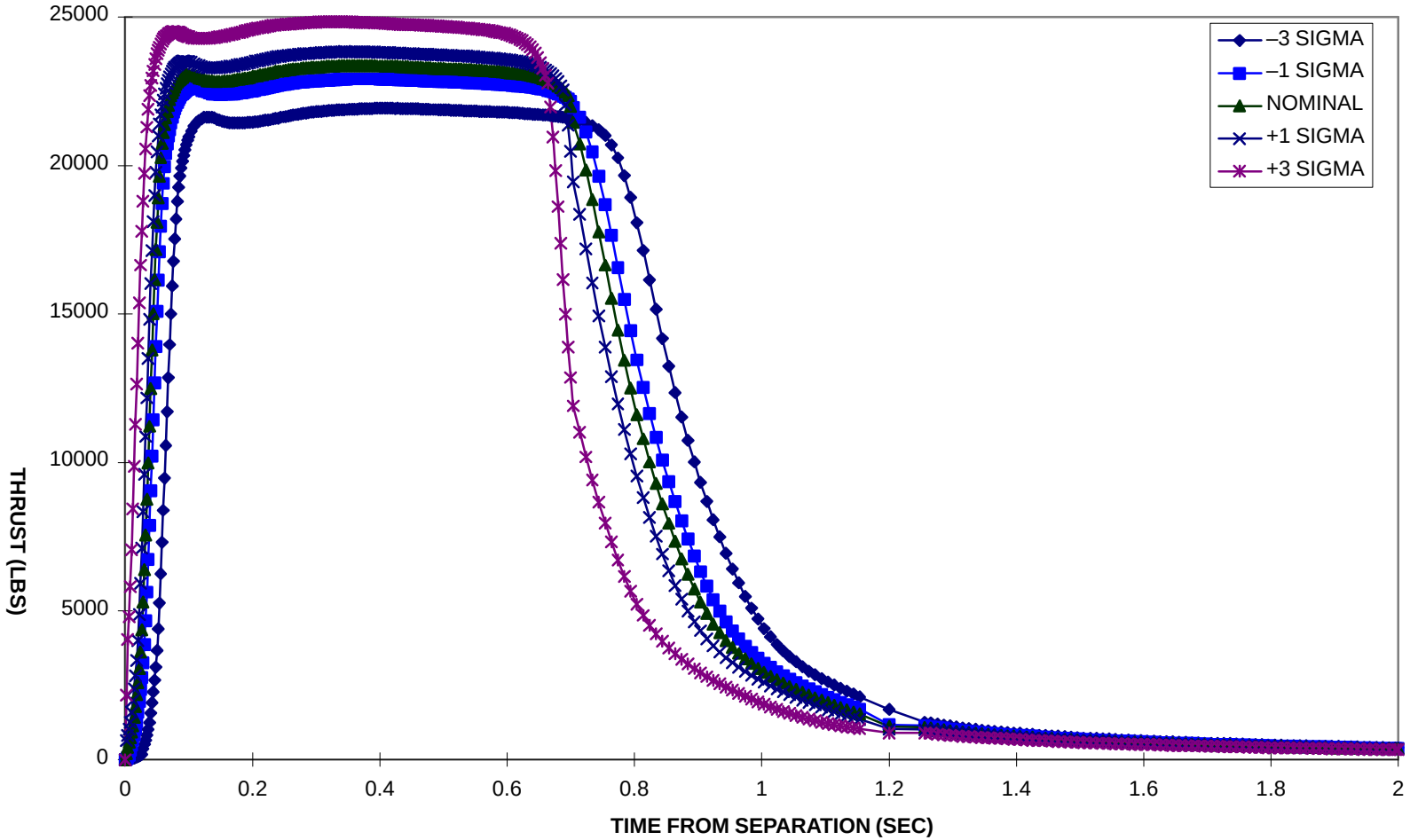


FIGURE 5-5-4

BSM THRUST PROFILE AT 110 PMBT

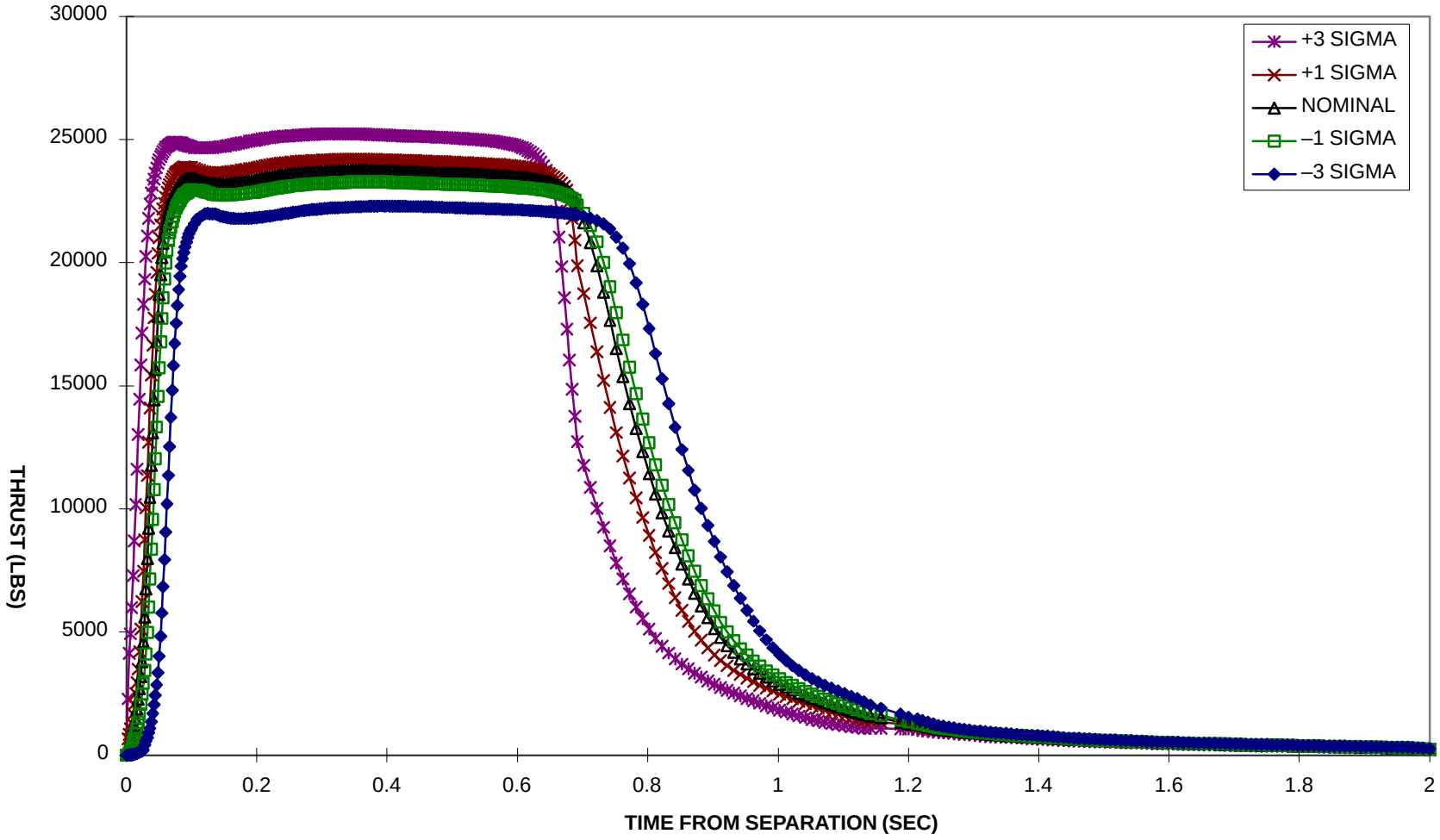


FIGURE 5-5-5

BSM THRUST PROFILE AT 120 PMBT

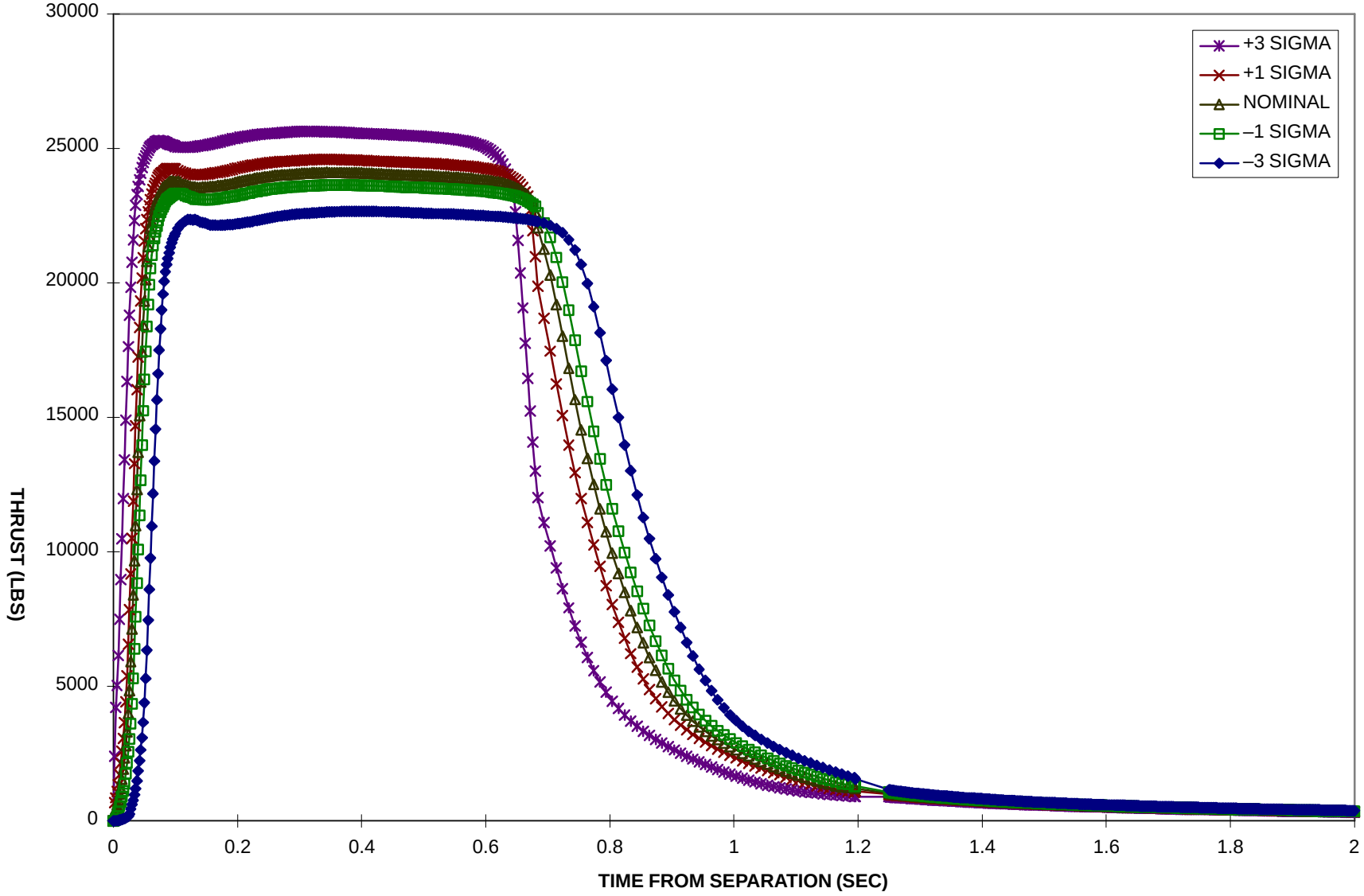


FIGURE 5-5-6

BSM THRUST PROFILE AT 100 F (WITH 10% MARGIN)

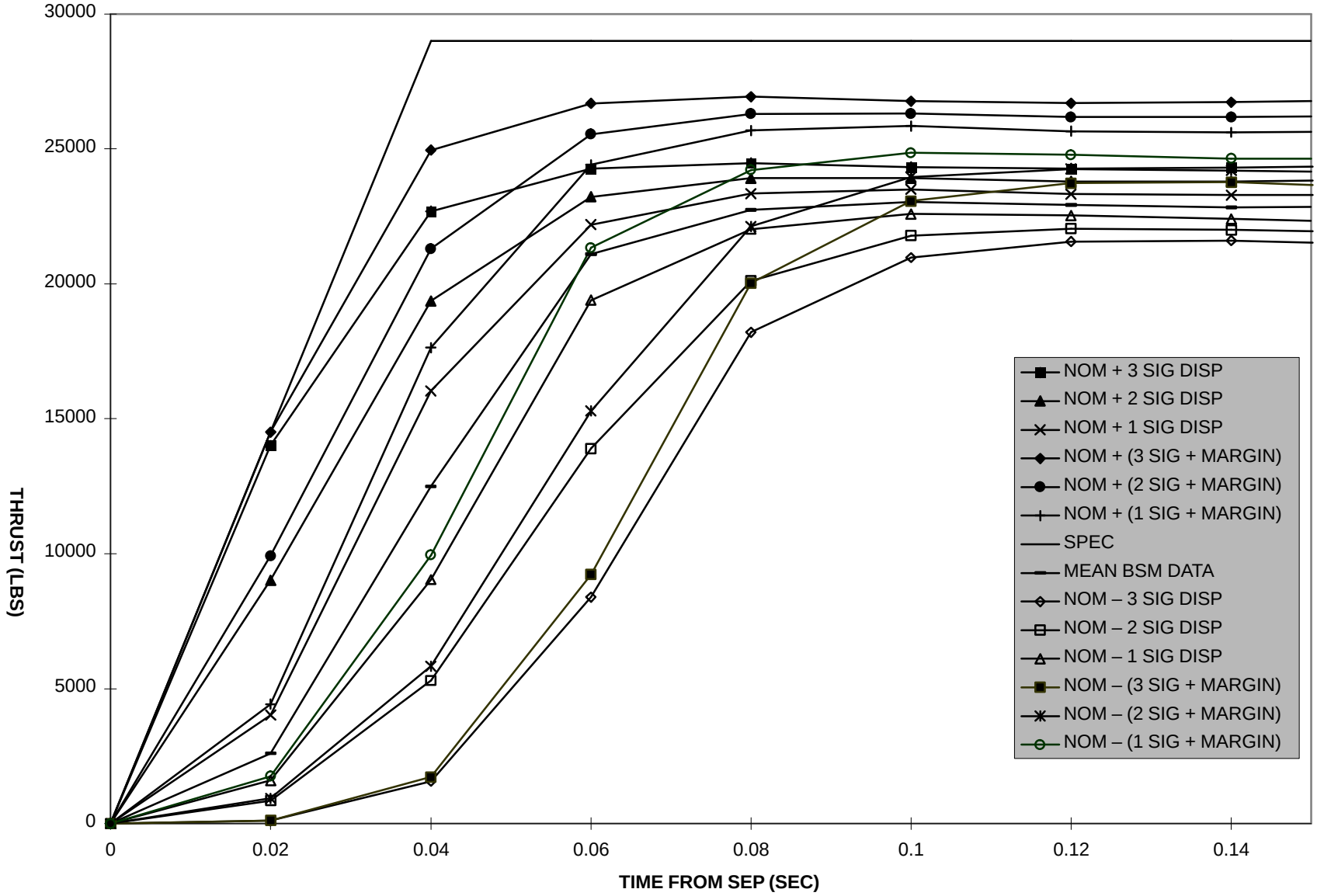


FIGURE 5-5-7

BSM THRUST PROFILE AT 110 F (WITH 10% MARGIN)

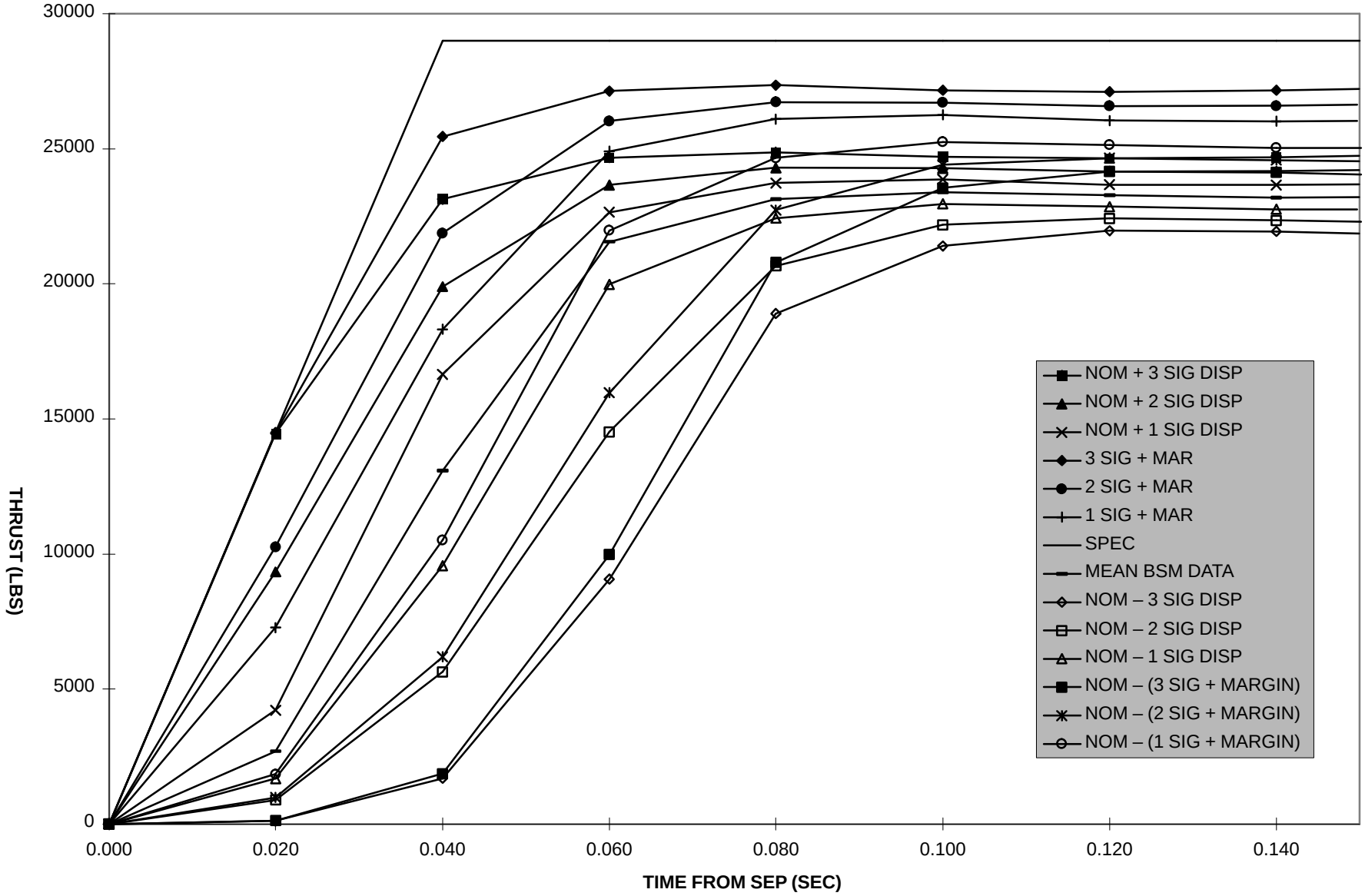


FIGURE 5-6 (DELETED)

FIGURE 5-7 (DELETED)

FIGURE 5-8 (DELETED)

FIGURE 5-9 (DELETED)

FIGURE 5-10 (DELETED)

FIGURE 5-11 (DELETED)

FIGURE 5-12 (DELETED)

FIGURE 5-13 (DELETED)

FIGURE 5-14

EIGHT-SECOND SSME SHUTDOWN THRUST

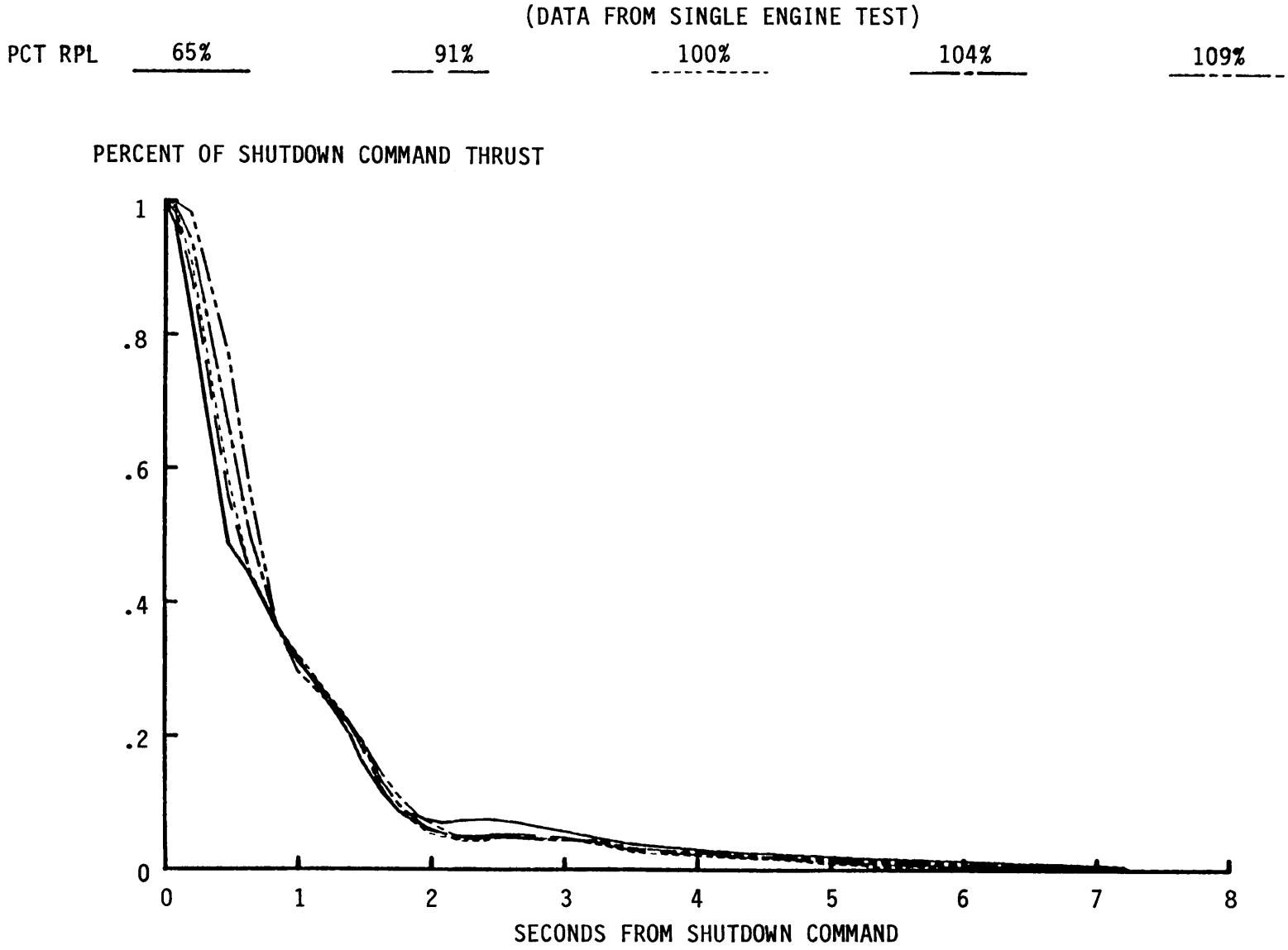
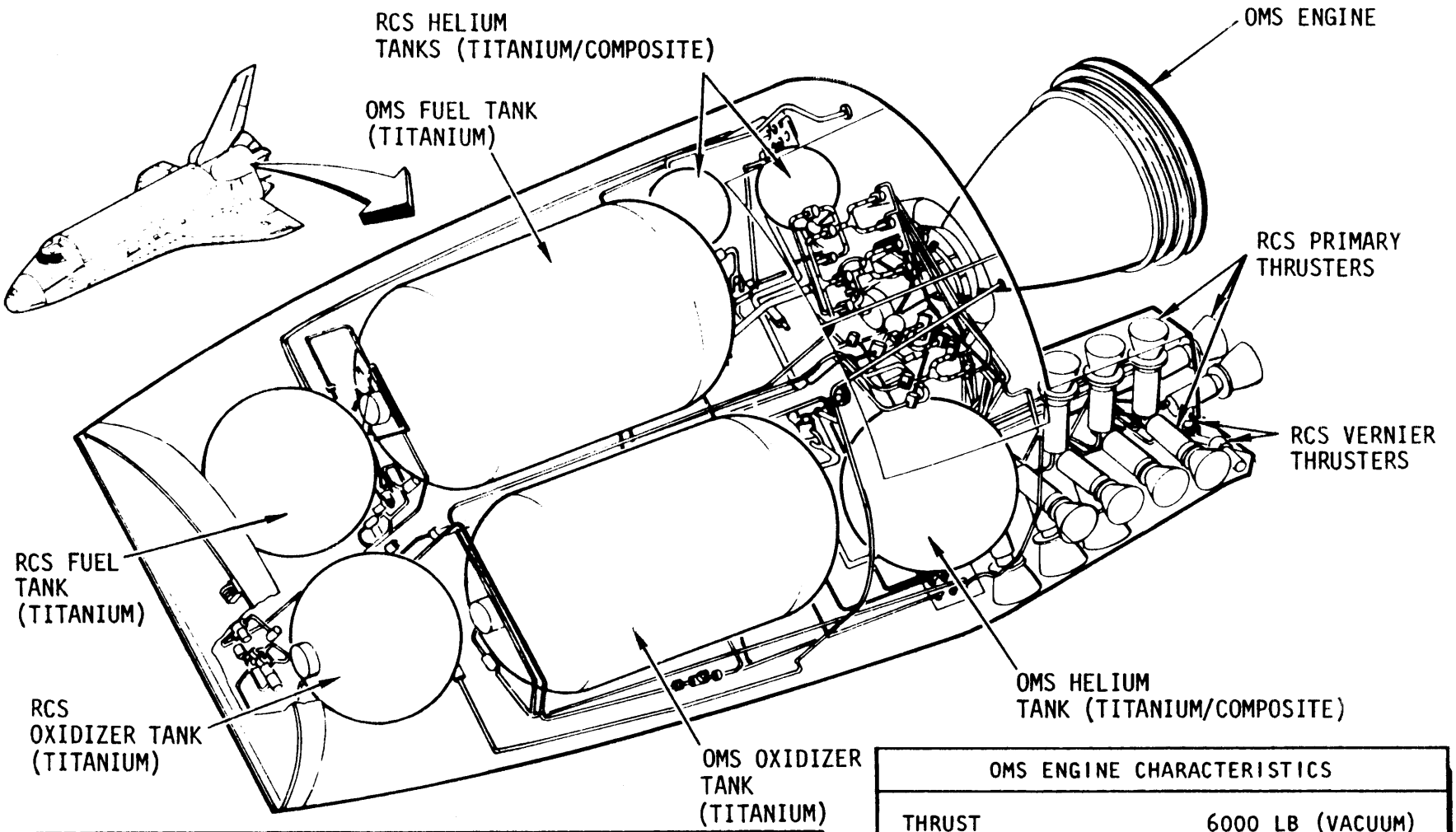


FIGURE 5-15

ORBITAL MANEUVER SUBSYSTEM



OMS ΔV CAPABILITY	1000 FT/SEC (65,000 LB PAYLOAD)
USEABLE OMS PROPELLANT:	23,876 LB TOTAL:
	14,866 LB N_2O_4
	9010 LB MMH

OMS ENGINE CHARACTERISTICS	
THRUST	6000 LB (VACUUM)
SPECIFIC IMPULSE	313.2 SEC
CHAMBER PRESSURE	125 PSIA
MIXTURE RATIO	1.65
GIMBAL CAPABILITY	±6° PITCH ±7° YAW

FIGURE 5-16

ORBITAL MANEUVER SUBSYSTEM SCHEMATIC

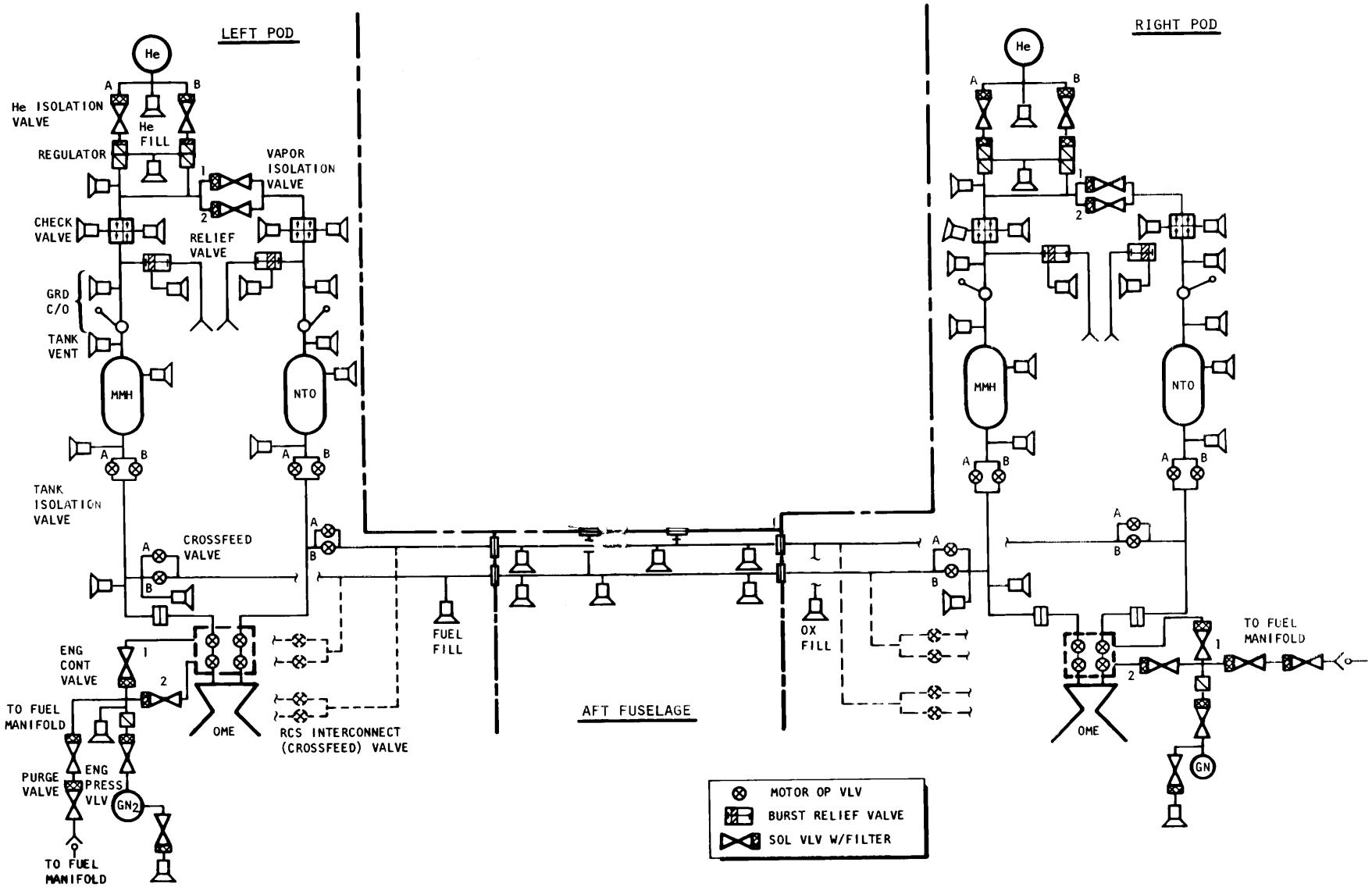


FIGURE 5-17

OMS ENGINE CHAMBER PRESSURE AND THRUST START TRANSIENT

SOURCE: SODB FIGURE 4.3.3-2

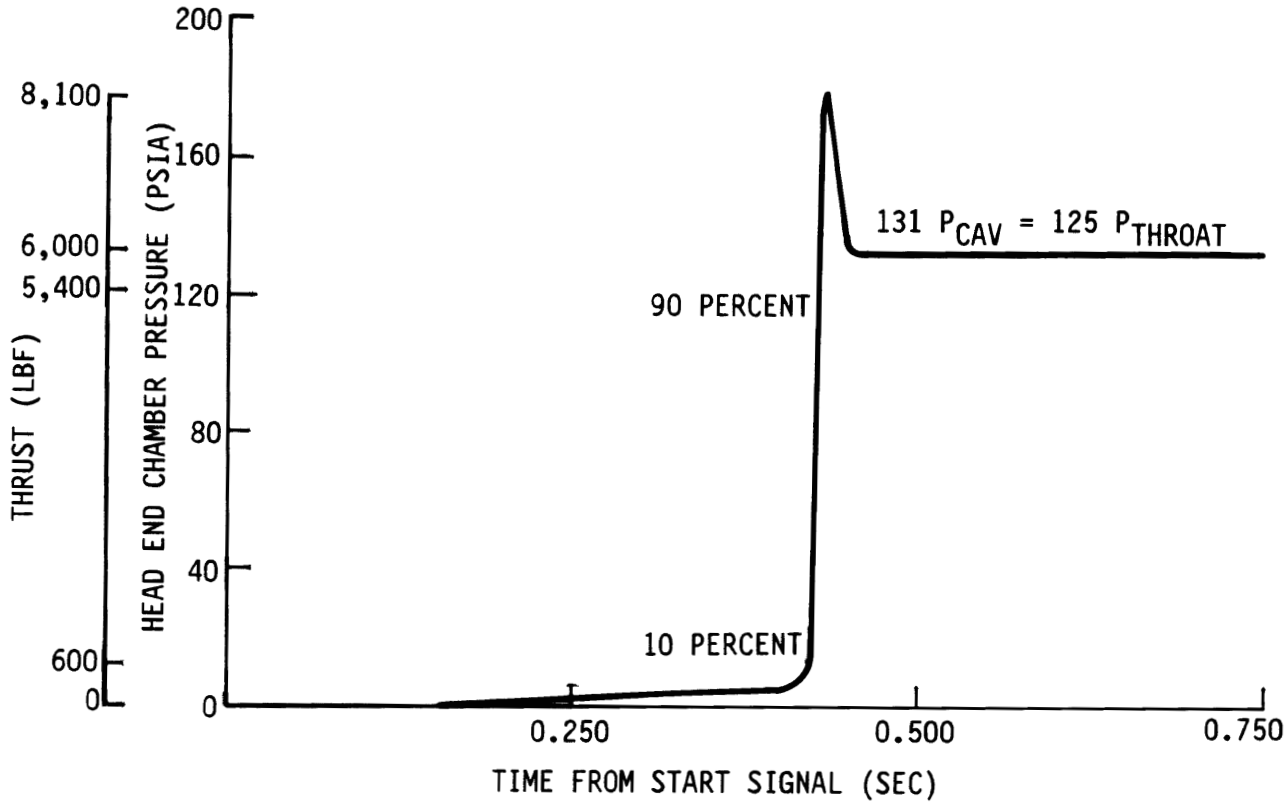


FIGURE 5-18

OMS ENGINE CHAMBER PRESSURE AND THRUST SHUTDOWN TRANSIENT

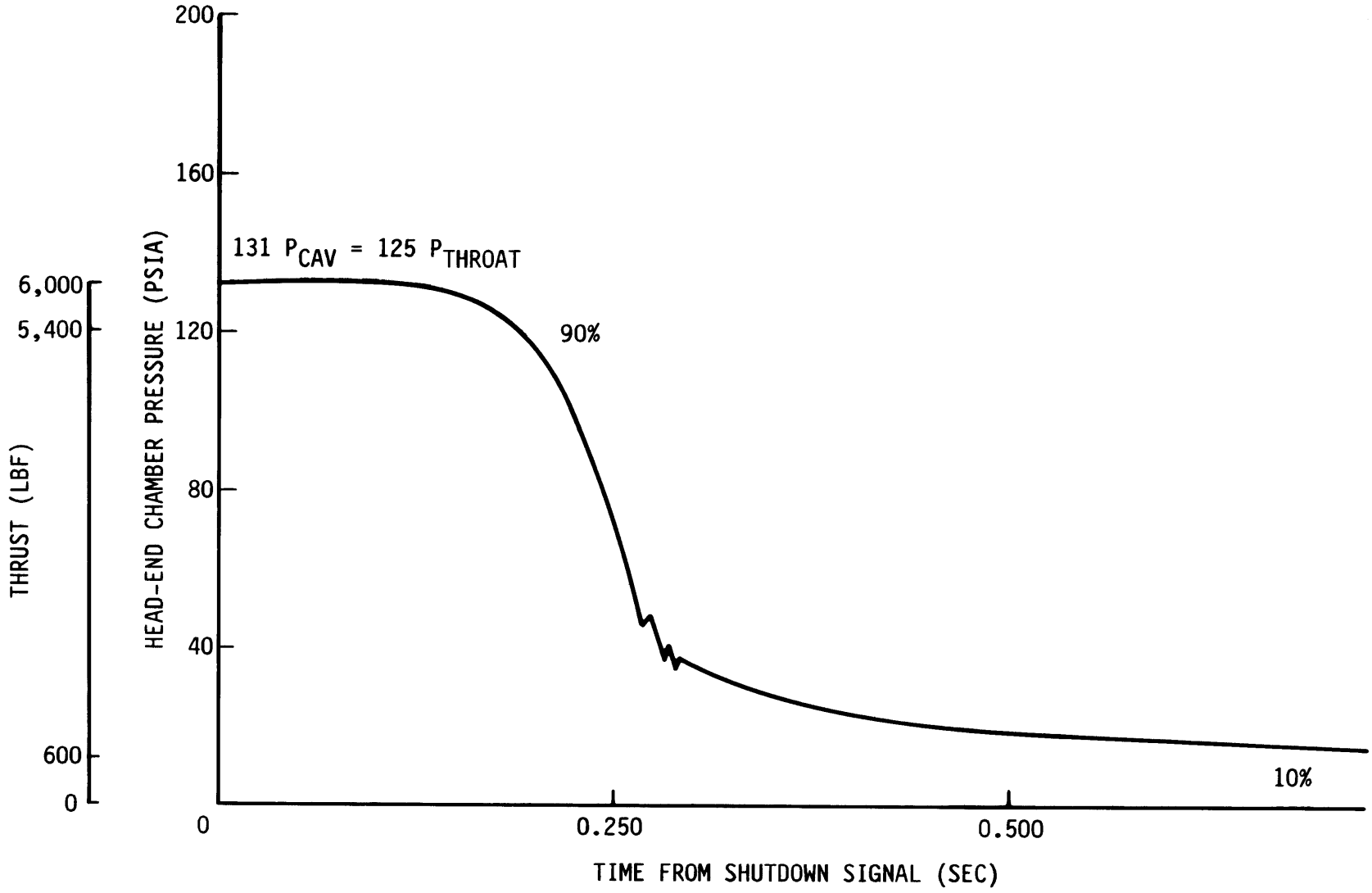


FIGURE 5-19

THRUST VECTOR MISALIGNMENT

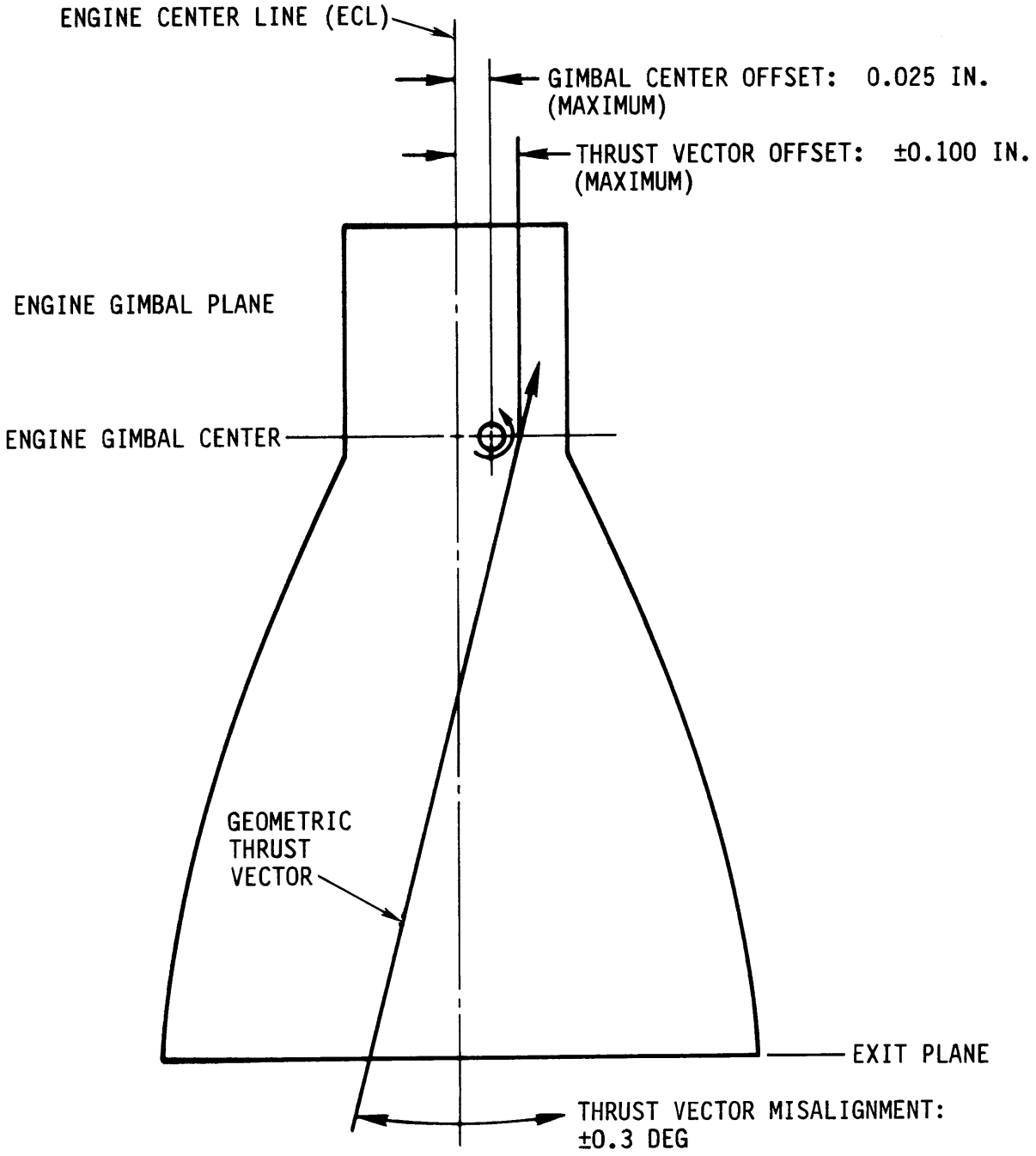


FIGURE 5-20

REACTION CONTROL SUBSYSTEM

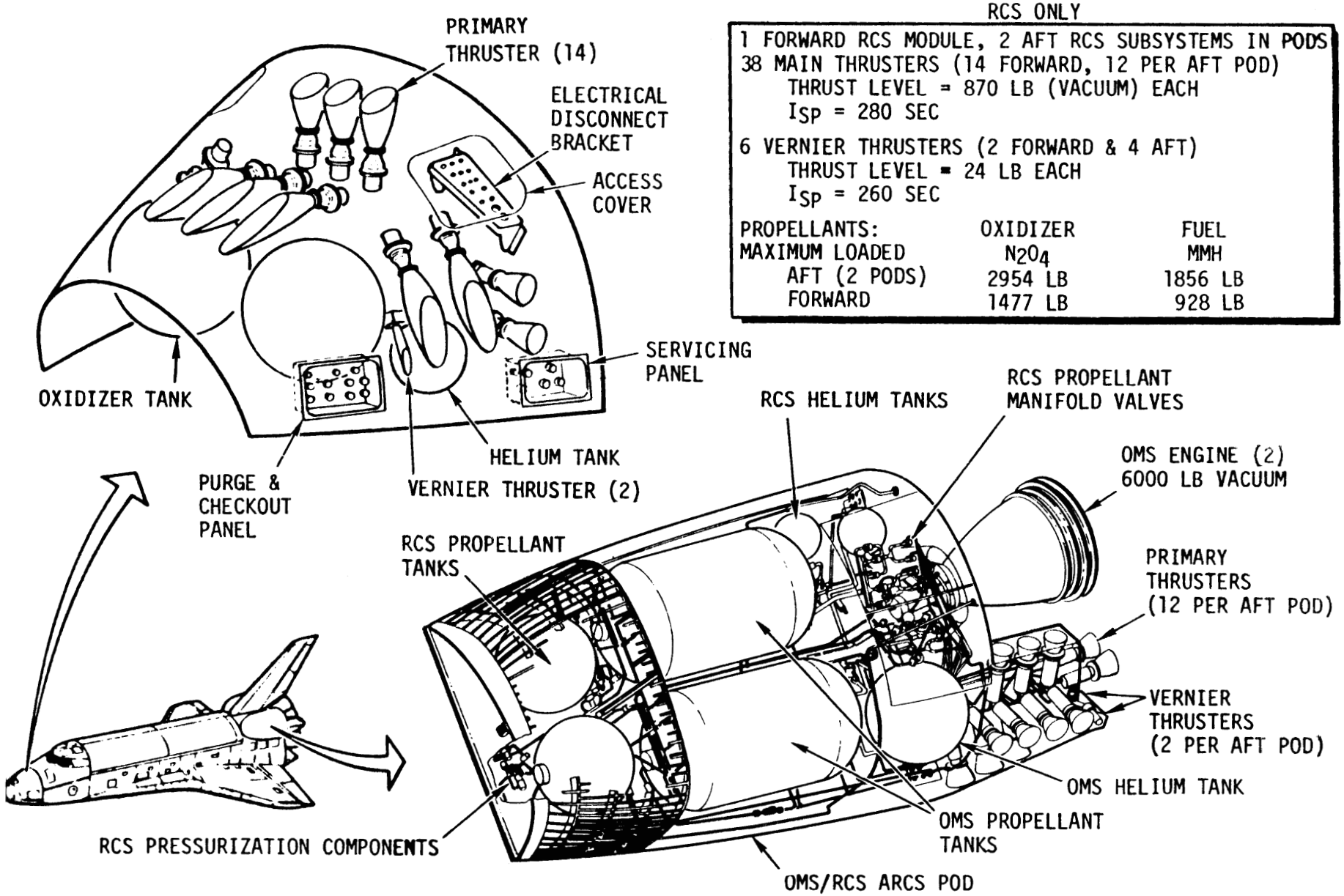


FIGURE 5-21

RCS SCHEMATICS

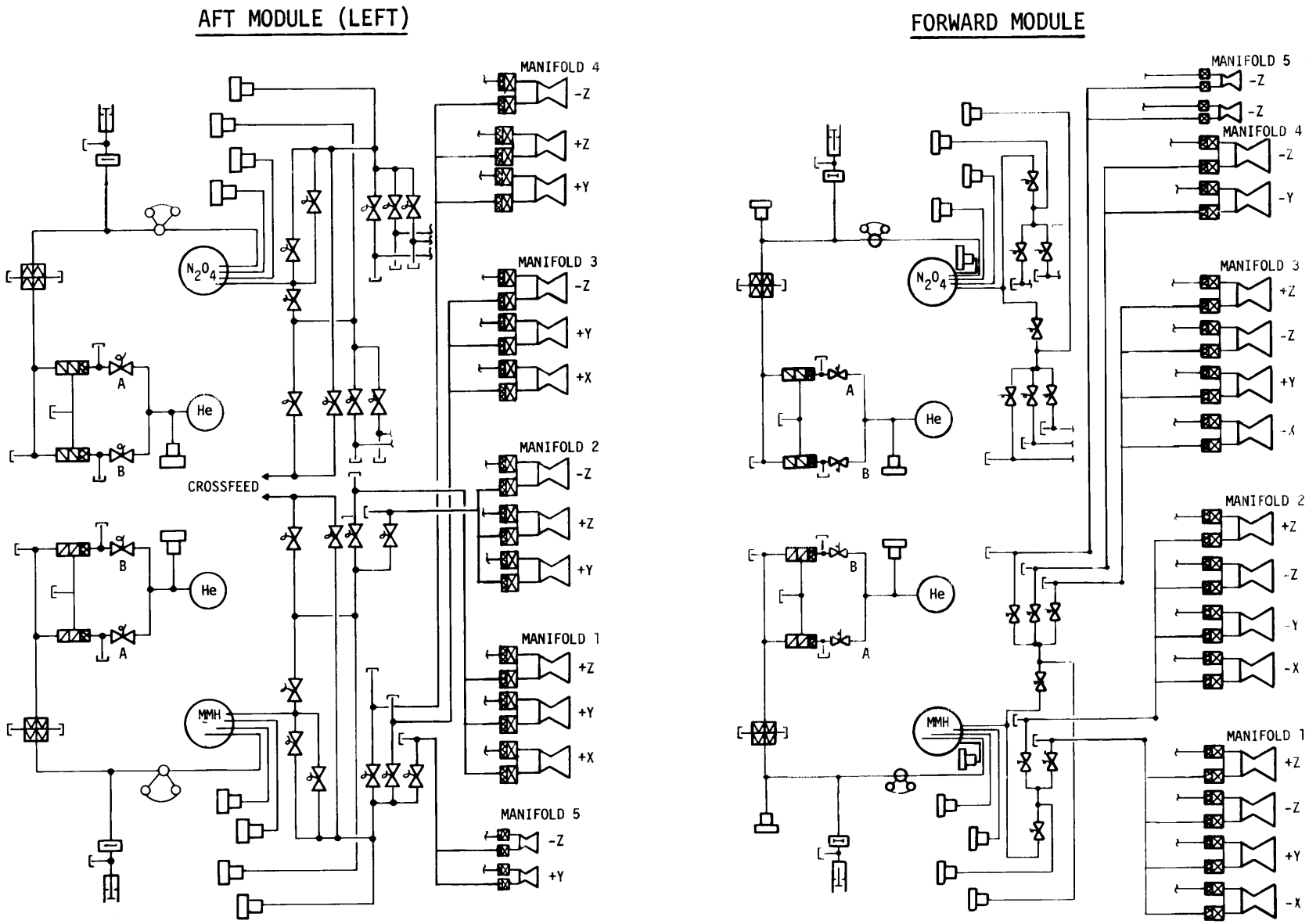


FIGURE 5-22

RCS THRUSTER IDENTIFICATION

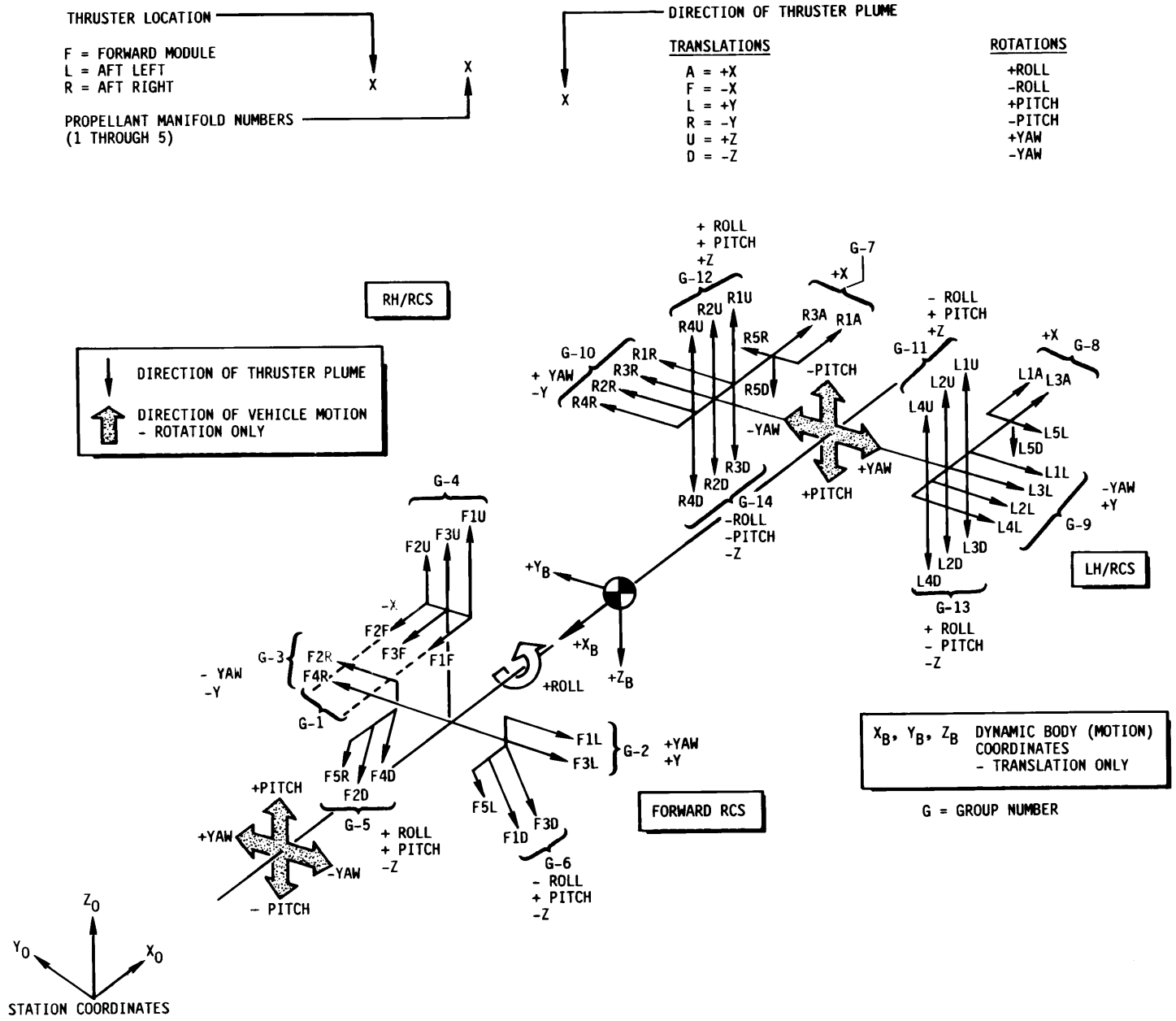


FIGURE 5-23

THRUST CORRECTION FACTOR FOR ALTITUDE (C_A) PRIMARY THRUSTERS

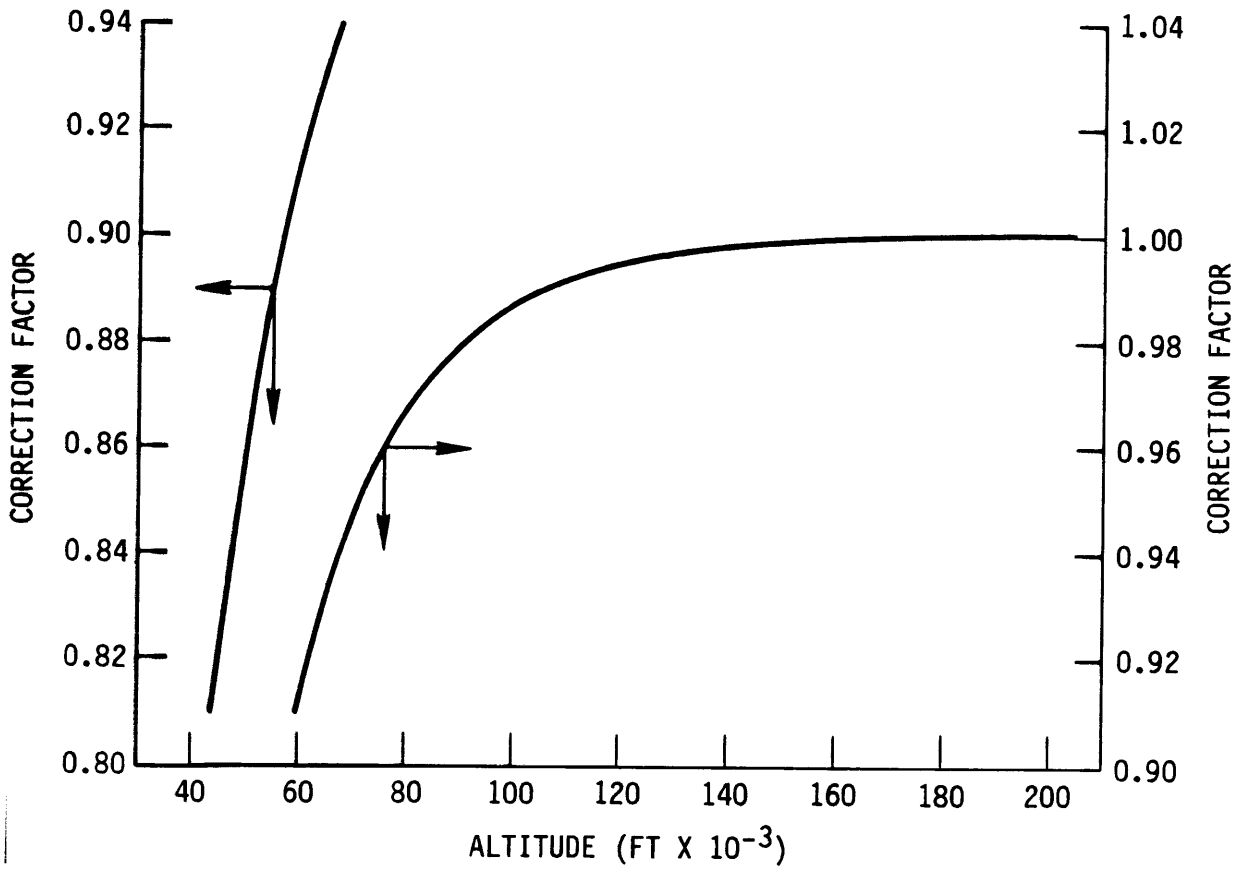


FIGURE 5-24

NOMINAL VACUUM THRUST SUMMARY

(Page 1 of 3)

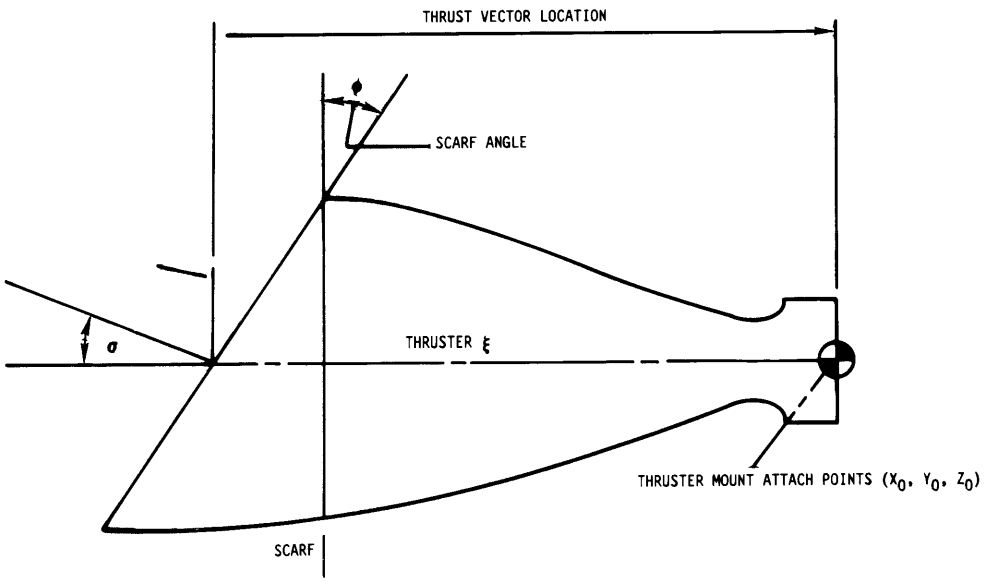


FIGURE 5-24

NOMINAL VACUUM THRUST SUMMARY

(Page 2 of 3)

Thruster Number	Thrust[a] Direction	Scarf Angle theta(deg)	Thrust Angle delta(deg)	Axial Component Thrust[f] (lb)	Radial Component Thrust[f] (lb)	Resultant Thrust[f] (F_t) (lb)	Thrust Vector[b] Location (in.)	Thruster Mount Attach Points (in.)		
								X_0	Y_0	Z_0
F2F	-X	64.8	7.93	879.4	122.6	887.9	20.56	327.277	14.654	392.955
F3F	-X	65.0	7.94	879.5	122.7	888.0	20.56	327.383	0.0	394.450
F1F	-X	64.8	7.93	879.4	122.6	887.9	20.56	327.277	-14.654	392.955
F1L	+Y	22.8	2.10	873.6	32.0	874.2	13.87	362.671	-55.631	373.728
F3L	+Y	15.4	1.38	870.3	21.0	870.6	13.07	364.708	-58.579	359.250
F2R	-Y	22.8	2.10	873.6	32.0	874.2	13.87	362.671	55.631	373.728
F4R	-Y	15.4	1.38	870.3	21.0	870.6	13.07	364.708	58.579	359.250
F2U	+Z	24.1	2.25	874.4	34.3	875.1	13.88	350.925	14.394	399.588
F3U	+Z	22.7	2.09	873.5	31.9	874.1	13.71	350.917	0.0	400.818
F1U	+Z	24.1	2.25	874.4	34.3	875.1	13.88	350.925	-14.394	399.588
F2D[c]	-Z	59.5	7.18	881.7	111.0	888.6	19.29	333.840	49.814	372.350
F1D[c]	-Z	59.5	7.18	881.7	111.0	888.6	19.29	333.840	-49.814	372.350
F4D[c]	-Z	57.8	6.96	879.3	107.4	885.9	18.93	348.440	54.839	373.566
F3D[c]	-Z	57.8	5.96	879.3	107.4	885.9	18.93	348.440	-54.839	373.566
F5R[c] (Vernier)	-Z	59.5	7.18	23.3	3.1	24.5	9.75	324.350	53.830	357.900
F5L[c] (Vernier)	-Z	59.5	7.18	23.3	3.1	24.5	9.75	324.450	-53.830	357.900
R3A[d]	+X	0.0	0.0	870.0	0.0	870.0	0.0	1,555.293	137.00	473.058
R1A[d]	+X	0.0	0.0	870.0	0.0	870.0	0.0	1,555.293	124.00	473.058
L3A[d]	+X	0.0	0.0	870.0	0.0	870.0	0.0	1,555.293	-137.00	473.058
L1A[d]	+X	0.0	0.0	870.0	0.0	870.0	0.0	1,555.293	-124.00	473.058
L4L	+Y	16.3	1.47	870.5	22.4	870.8	13.10	1,516.00	-136.77	459.00
L2L	+Y	16.3	1.47	870.5	22.4	870.8	13.10	1,529.00	-136.77	459.00
L3L	+Y	16.3	1.47	870.5	22.4	870.8	13.10	1,542.00	-136.77	459.00
L1L	+Y	16.3	1.47	870.5	22.4	870.8	13.10	1,555.00	-136.77	459.00
R4R	-Y	16.3	1.47	870.5	22.4	870.8	13.10	1,516.00	136.77	459.00

FIGURE 5-24

NOMINAL VACUUM THRUST SUMMARY

(Page 3 of 3)

Thruster Number	Thrust[a] Direction	Scarf Angle theta(deg)	Thrust Angle delta(deg)	Axial Component Thrust[f] (lb)	Radial Component Thrust[f] (lb)	Resultant Thrust[f] (F_t) (lb)	Thrust Vector[b] Location (in.)	Thruster Mount Attach Points (in.)		
								X_0	Y_0	Z_0
R2R	-Y	16.3	1.47	870.5	22.4	870.8	13.10	1,529.00	136.77	459.00
R3R	-Y	16.3	1.47	870.5	22.4	870.8	13.10	1,542.00	136.77	459.00
R1R	-Y	16.3	1.47	870.5	22.4	870.8	13.10	1,555.00	136.77	459.00
L4U	+Z	0.0	0.0	870.0	0.0	870.0	0.0	1,516.00	-132.00	480.50
L2U	+Z	0.0	0.0	870.0	0.0	870.0	0.0	1,529.00	-132.00	480.50
L1U	+Z	0.0	0.0	870.0	0.0	870.0	0.0	1,542.00	-132.00	480.50
R4U	+Z	0.0	0.0	870.0	0.0	870.0	0.0	1,516.00	132.00	480.50
R2U	+Z	0.0	0.0	870.0	0.0	870.0	0.0	1,529.00	132.00	480.50
R1U	+Z	0.0	0.0	870.0	0.0	870.0	0.0	1,542.00	132.00	480.50
L4D[e]	-Z	0.0	0.0	870.0	0.0	870.0	0.0	1,516.00	-111.945	437.403
L2D[e]	-Z	0.0	0.0	870.0	0.0	870.0	0.0	1,529.00	-111.00	440.00
L3D[e]	-Z	0.0	0.0	870.0	0.0	870.0	0.0	1,542.00	-111.055	442.597
R4D[e]	-Z	0.0	0.0	870.0	0.0	870.0	0.0	1,516.00	111.945	437.403
R2D[e]	-Z	0.0	0.0	870.0	0.0	870.0	0.0	1,529.00	111.00	440.00
R3D3	-Z	0.0	0.0	870.0	0.0	870.0	0.0	1,542.00	111.055	442.597
L5D (Vernier)	-Z	0.0	0.0	24.0[g]	0.0	24.0[g]	0.0	1,565.00	-118.00	455.44
R5D (Vernier)	-Z	0.0	0.0	24.0[g]	0.0	24.0[g]	0.0	1,565.00	118.00	455.44
R5R	-Y	16.3	1.47	24.0	0.6	24.0	6.19	1,565.00	143.68	459.00
L5L	+Y	16.3	1.47	24.0	0.6	24.0	6.19	1,565.00	143.68	459.00

[a]Translational direction.

[b]Distance from mount attach point, along thruster centerline.

[c]Canted 37° outboard in the Y-Z plane.

[d]Canted up 10° in the X-Y plane.

[e]Canted aft 12° in the X-Y plane and 20° outboard in the Y-Z plane.

[f]For impingement effects above 475,000 feet, refer to Aerodynamic Design Data Book, Vol. I (SD72-SH-0060-IL-7 Appendix C).

[g]For impingement effects, refer to EX32/8202-24.

FIGURE 5-25

SRB SOLID ROCKET MOTOR

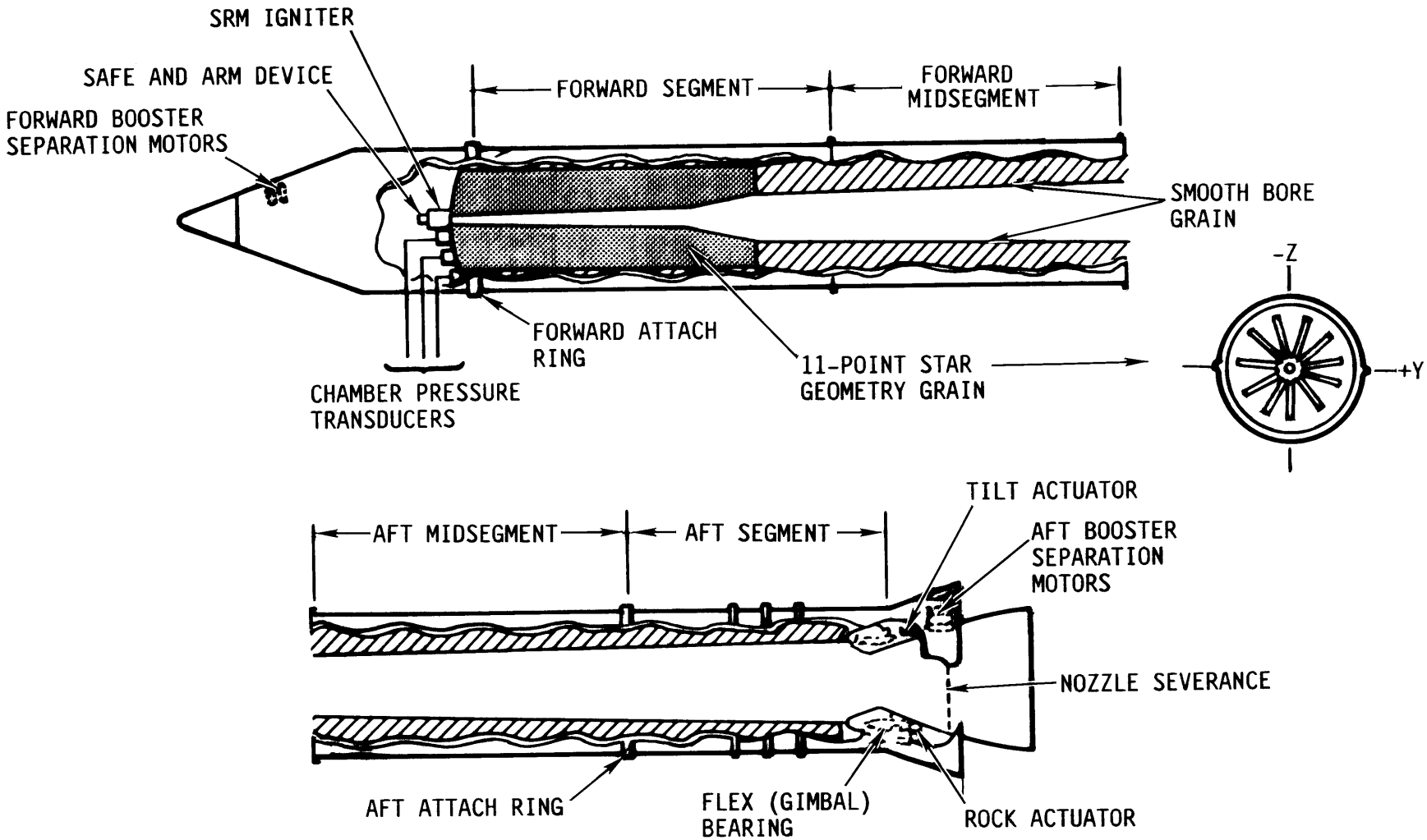


FIGURE 5-26

GEOMETRIC THRUST VECTOR

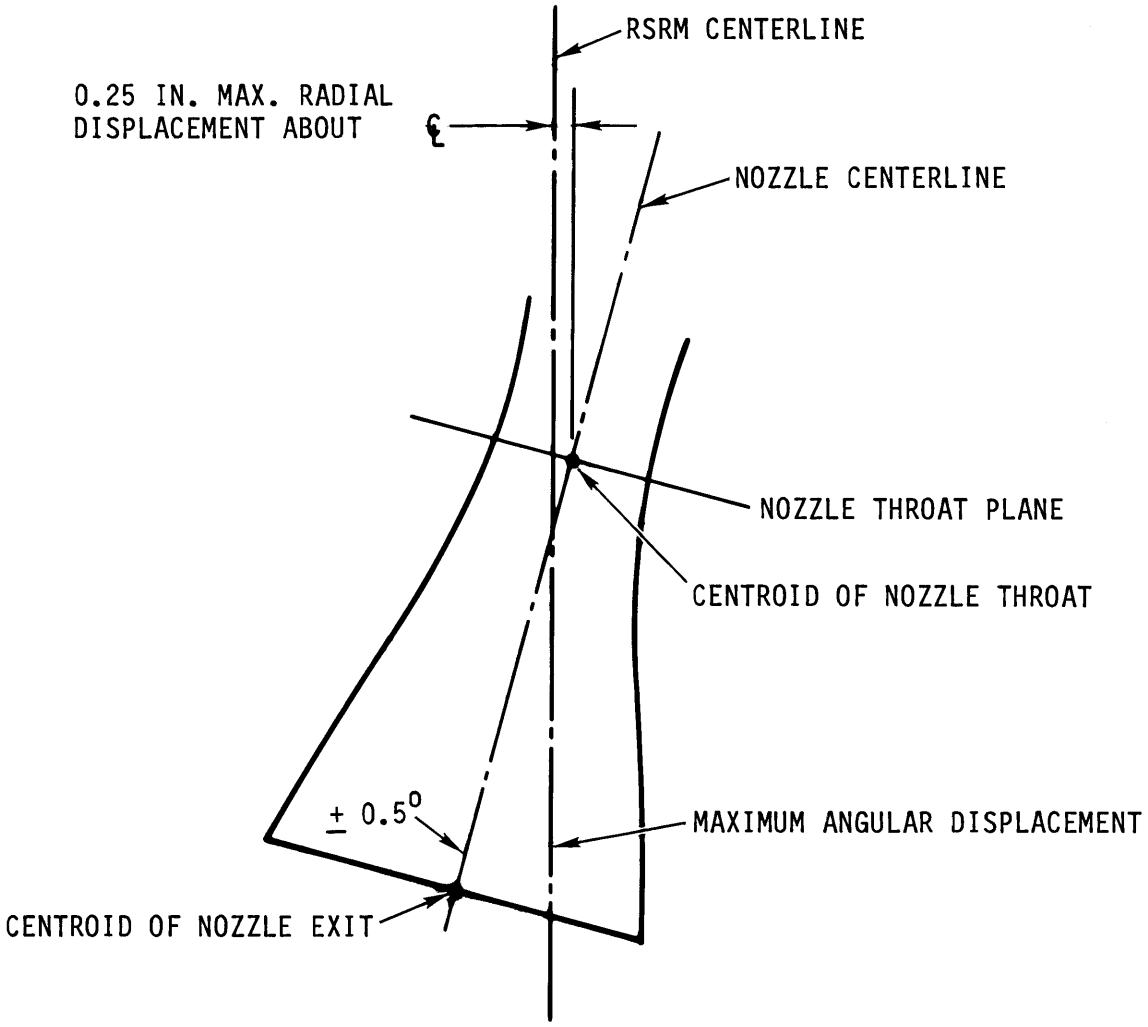
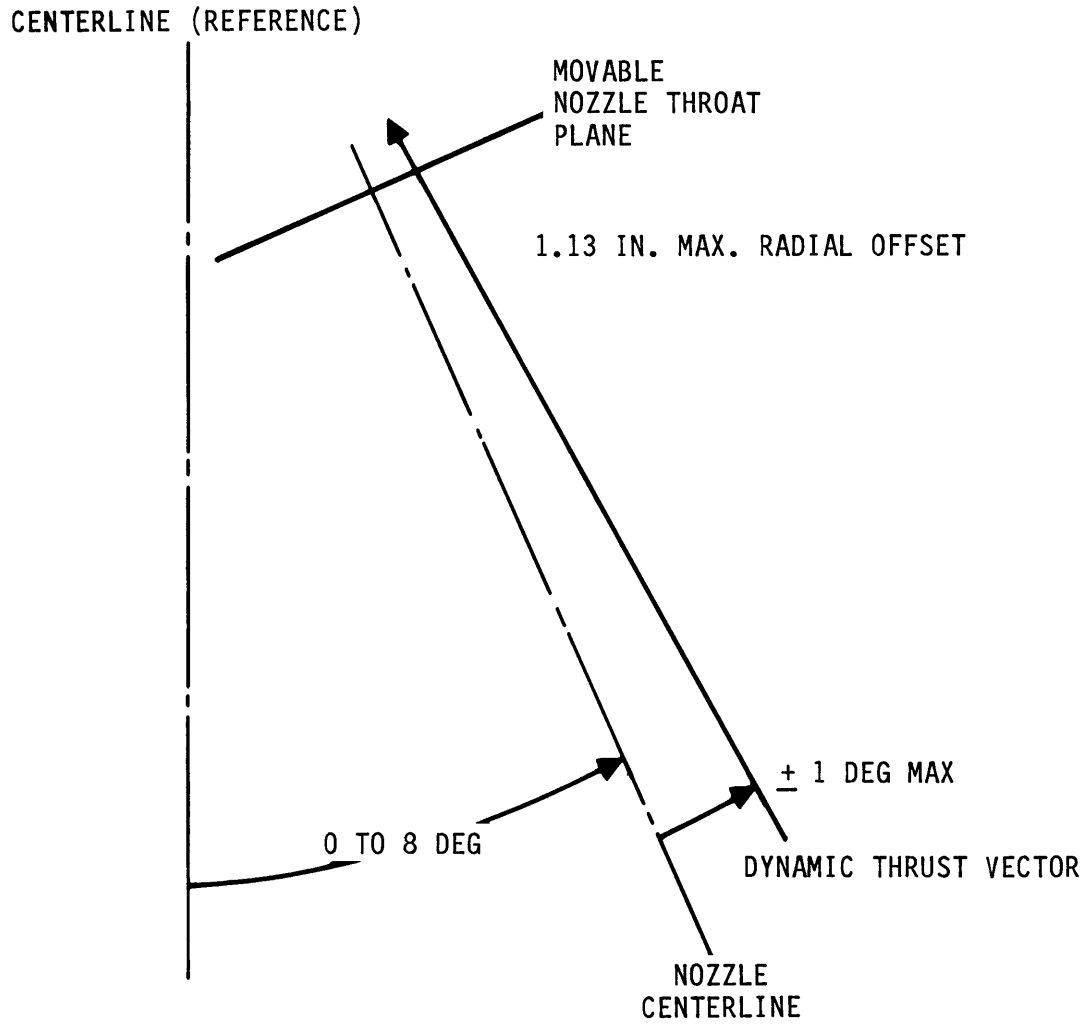


FIGURE 5-27

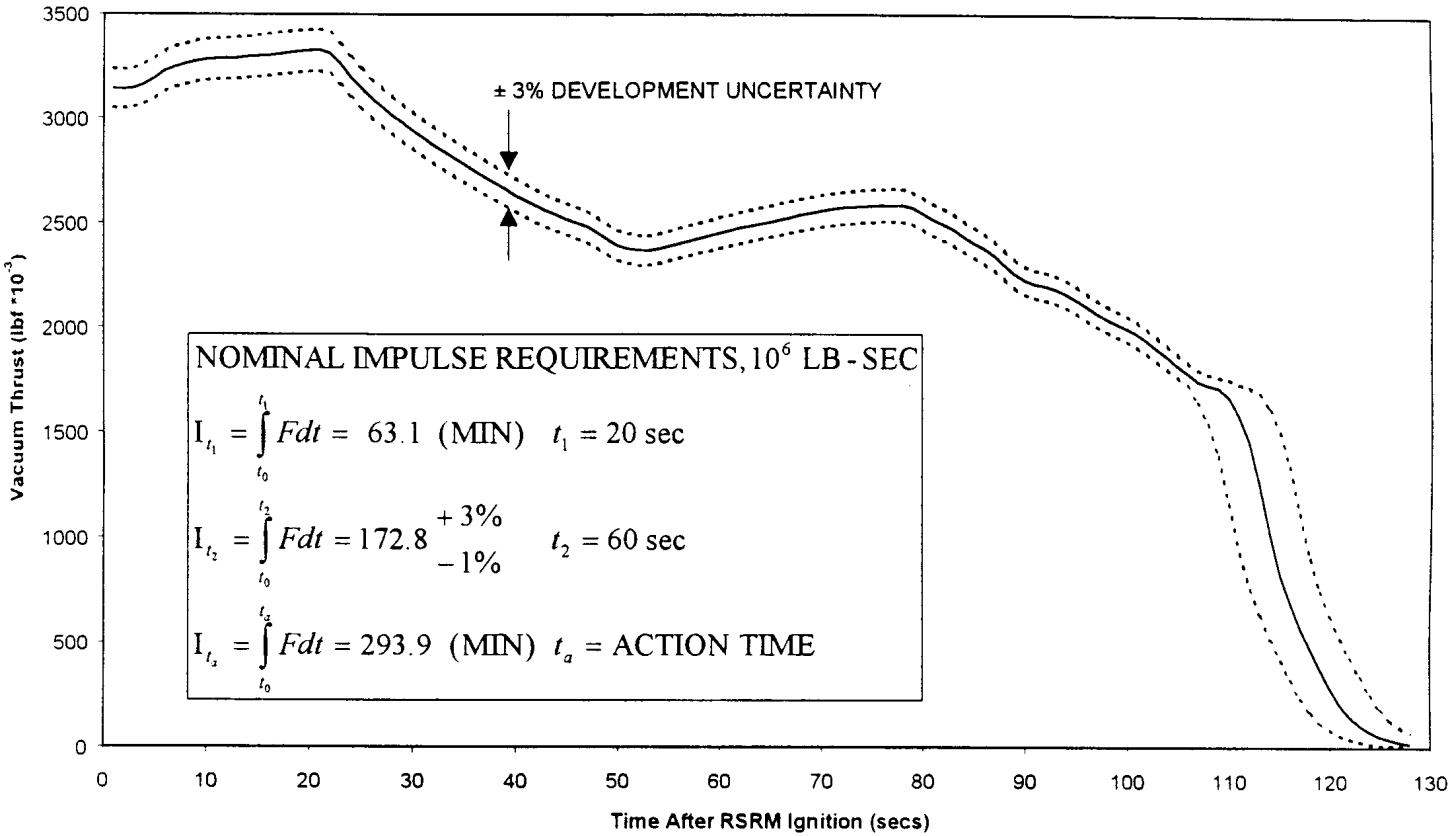
DYNAMIC THRUST VECTOR



DYNAMIC THRUST VECTOR REQUIREMENT (NOZZLE IN ANY DEFLECTED POSITION UP TO $\pm 8^{\circ}$ AND AT ANY PRESSURE FROM T +4 TO T +108 SECONDS)

FIGURE 5-28

RSRM NOMINAL PERFORMANCE REQUIREMENTS (VACUUM, 60°F PMBT)



NOTE: The nominal thrust-time curve of the qualified RSRM must fall within the predictability envelope and is further constrained by the total impulse requirement.

FIGURE 5-29

IGNITION THRUST IMBALANCE

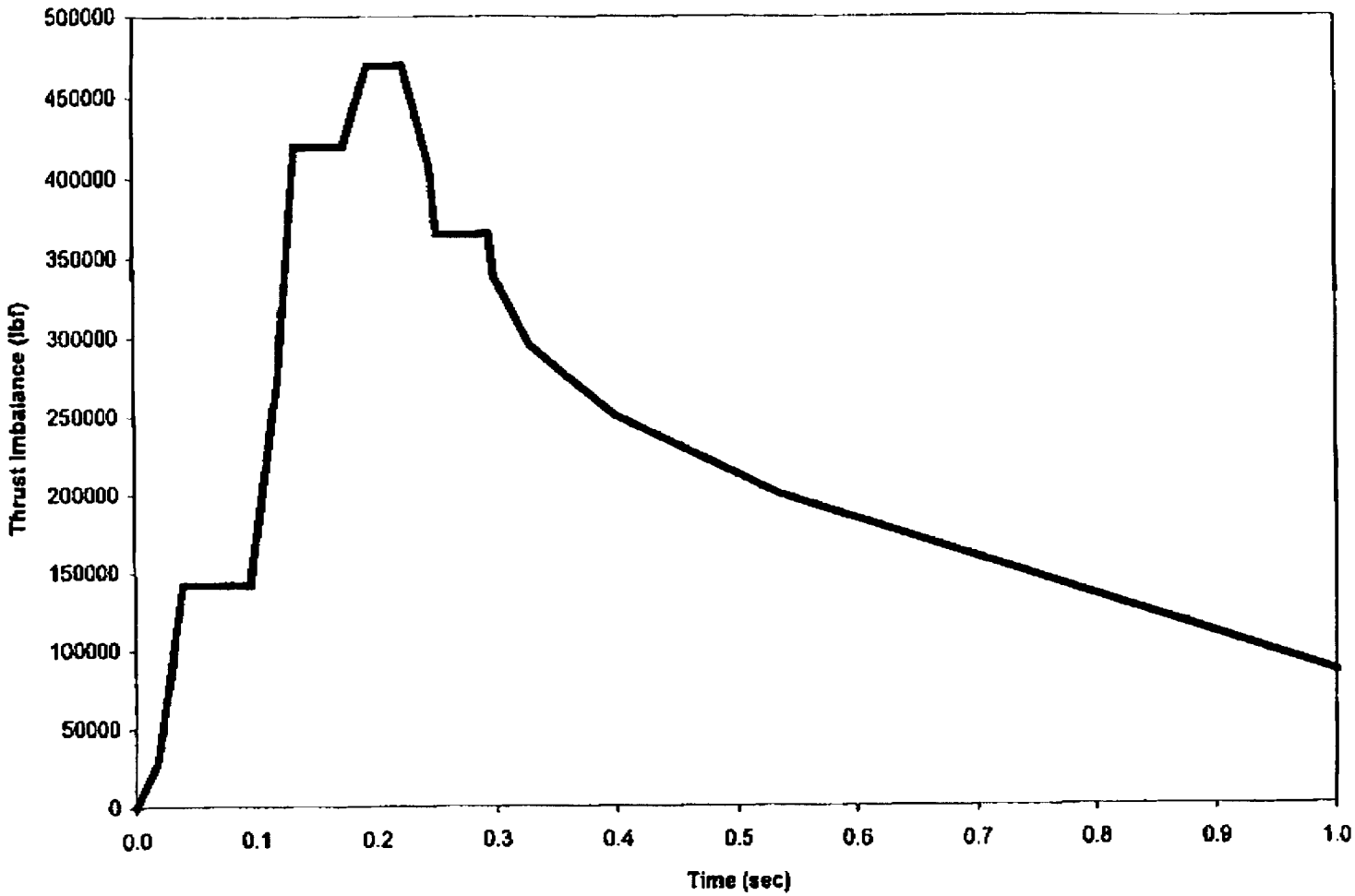
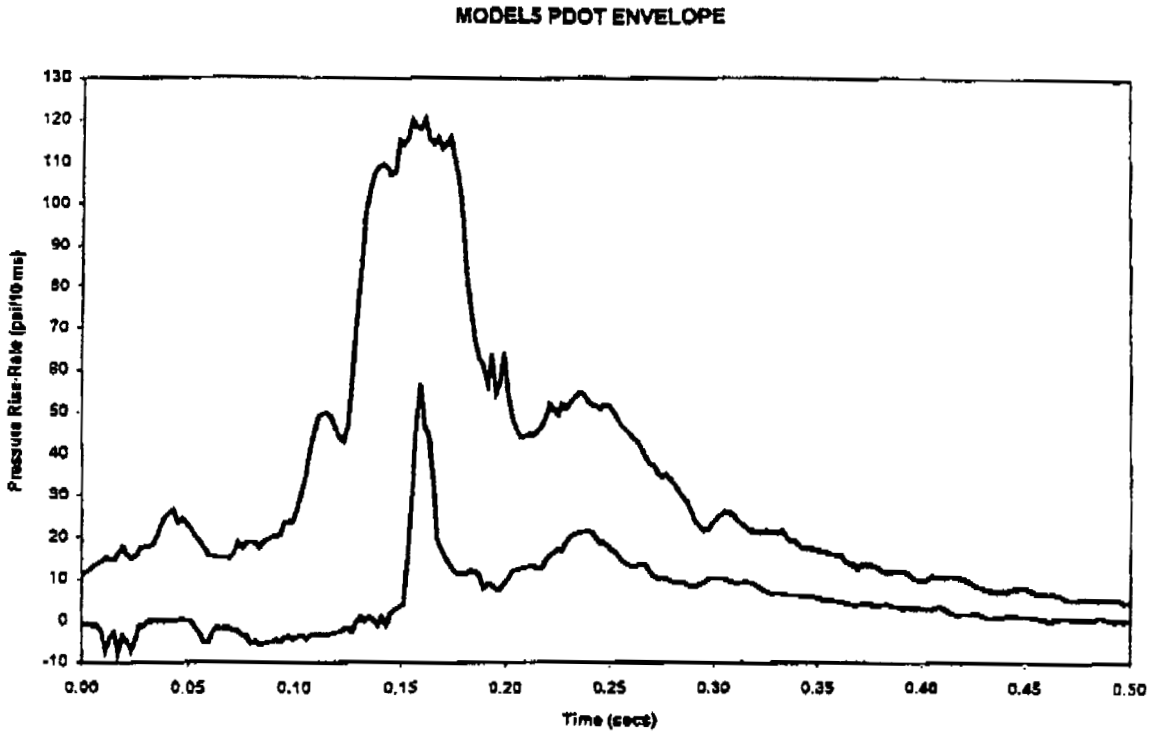


FIGURE 5-30

IGNITION MODEL MAXIMUM/MINIMUM PRESSURE RISE RATE ENVELOPE*



NOTES: (1) THE AREAS FROM 0-100 MS AND 300-500 MS ARE NOT SIGNIFICANT TO COMPUTED LIFT-OFF LOADS RESPONSE.

(2) THESE PRESSURE RISE RATE ENVELOPES ARE BASED ON AN IGNITION PEAK PRESSURE RISE TIME OF 0.155 SEC. FOR AN OFF-NOMINAL IGNITION PEAK PRESSURE RISE RATE TIME, THE CURVES ARE SHIFITED AN EQUIVALENT AMOUNT OF TIME.

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