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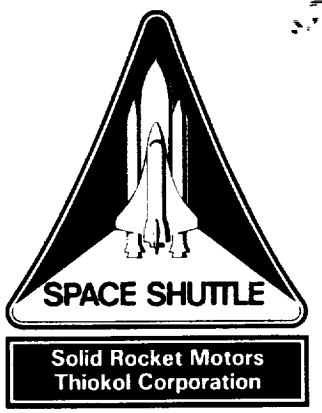

TWR-17550-10

RSRM-11 (360W011) FINAL REPORT
BALLISTICS MASS PROPERTIES (STS-35)

21 January 1991

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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1.0 INTRODUCTION

This report contains the propulsion performance and reconstructed mass properties data from Thiokol's RSRM-11 motors which were assigned to the STS-35 launch. The Thiokol manufacturing designations for the motors were 360W011A/360W011B, which are referred to in this report as RSRM-11A and RSRM-11B, respectively. All of the segments for the motor were cast from the same propellant evaluation except for the RSRM-11B aft segment. It was originally cast as the RSRM-12A aft segment, but a nozzle joint leak check problem forced a switch out of the aft segments. The launch of STS-35 occurred on 2 December 1990 at the Eastern Test Range (ETR). The data contained herein was input to the STS-35 Flight Evaluation Report.

The SRM propellant, TP-H1148, is a composite type solid propellant, formulated of polybutadiene acrylic acid acryonitrile terpolymer binder (PBAN), epoxy curing agent, ammonium perchlorate oxidizer and aluminum powder fuel. A small amount of burning rate catalyst (iron oxide) was added to achieve the desired propellant burn rate. The propellant evaluation and raw material information for the RSRM-11 are included in the discussion section of this report.

The propellant grain design consists of four segments. There is a forward segment with an eleven point star with a transition into a tapered circular perforated (CP) configuration. There are two center segments that result in a double tapered CP configuration and an aft segment with a triple taper CP configuration and a cutout for the partially submerged nozzle (Figure 1.1).

The ballistic performance presented in this report was based on the Operational Flight Instrumentation (OFI) 12.5 sample per second pressure data for the steady state and tail off portion of the pressure trace. The 12.5 s/sec OFI data on the left and right motor, gauges B47P1302C and B47P2302C, respectively, were adjusted down by 0.2 percent to closer match the other motor OFI gauges on each motor. Recent studies have shown that the transducers are affected by the measuring system at KSC and temperature gradients created by the igniter heaters. These factors

often shift the ambient offset up or down. Therefore, an adjustment to the data from each transducer is made to make the initial reading match the atmospheric pressure at the time of launch. The atmospheric pressure at the time of launch at KSC was 14.84 psia. In addition, the data for both motors were adjusted up by 1% from 0 to 1 seconds and ramped down from 1.0% to 0.4% from 1-2 seconds and then adjusted up 0.4% thereafter. These adjustments are a result of a bias between the OPT and Taber pressure transducers which are used on flights and static tests respectively. No high sample rate pressure gauges, Development Flight Instrumentation (DFI), were used on this flight and therefore no ignition data will be presented.

2.0 SUMMARY

The delivered propellant burn rates were lower than predicted. The delivered burn rates were 0.367 in/sec and 0.366 in/sec at 625 psia and 60°F for the left and the right RSRM, respectively. The predicted burn rates were 0.368 in/sec and 0.369 in/sec for the left and right motors, respectively. The average of the two motors was 0.41% lower than the target burn rate of 0.368 in/sec at 625 psia and 60°F. Although the delivered burn rates were slightly lower than predicted, they were well within the historical database. The performance of the two motors was very close as can be seen in Figure 2.1.

The performance of the pair of motors were compared to the following CEI Specification CPW1-3600A paragraphs for compliance: 3.2.1 Performance, 3.2.1.1 General Performance, 3.2.1.1.2 Motor Characteristics, 3.2.1.1.2.1 Nominal Thrust Time Curve, 3.2.1.1.2.2 Performance Tolerance and Limits, 3.2.1.1.2.4 Impulse Gates and 3.2.1.1.2.3 Thrust Differential. The aspects of the CEI Specification that could not be compared due to low sampling of the data were 3.2.1.1.1 Ignition Characteristics, 3.2.1.1.1.1 Ignition Interval and 3.2.1.1.1.2 Pressure Rise Rate. The performance from each motor as well as matched pair performance values were well within the CEI Specification

requirements. The nominal thrust time curve and impulse gate information was updated to include RSRM-11. The updated historical average was well within the variation limits developed from the RSRM Block prediction population at a burn rate of 0.368 in/sec at 625 psia and 60°F. The block nominal population consists of the following motors: DM-8, DM-9, QM-6, QM-7, PVM-1, QM-8 and RSRM-1 through RSRM-4. The historical population values are the average performance data from DM-8, DM-9, QM-6, QM-7, QM-8, PVM-1, and RSRM-1 through RSRM-11. Several motors are excluded from the population average due to segment swap outs. The effects of the mismatched aft segment on RSRM-11B can be seen in Figure 2.1. It appears the aft segment, which had propellant from a different set of raw materials, had a higher burn rate than the rest of the motor. As a result of the higher burn rate, the segment burned out sooner and caused a dip in the performance trace at about 103 seconds. This slight change in performance did not cause any performance parameters to exceed the historical database or specification limits.

Post flight reconstructed RSRM mass properties are within expected values for the RSRM welterweight (RSRMW) configurations and meet the following CEI paragraphs:3.2.2.2, 3.2.2.2.1, 3.2.2.2.2, and 3.2.2.2.3.

3.0 DISCUSSION AND RESULTS

3.1 RSRM-11 PROPELLANT MATERIALS

Both of the RSRM-11 flight motors were cast with primarily one evaluation of propellant, F67. The exceptions are the RSRM-11B aft segment which is the as-cast RSRM-12A aft segment (evaluation F68), and 2 verification mixes in the RSRM-11A center forward and RSRM-11B forward segments (evaluation F72). An evaluation is defined as a specific combination of raw material lots and all of the standardization and production batches of propellant produced with these materials. Table 3.1 shows the raw material lots and vendors for the evaluations used. The igniters used in this flight set were cast from propellant evaluation

F70, mix F700004. See document TWR-19068 for more information on propellant materials for this flight set. For more information on this lot of igniters see lot acceptance test (LAT) 41 test report (TWR-50058).

3.2 RSRM PROPULSION PERFORMANCE ANALYSIS

All times shown in this section, unless noted otherwise are referenced to the RSRM ignition command time at 90:336:06:49:01:022(GMT). As previously mentioned the OFI (12.5 s/s) data was used for the steady state and tailoff performance assessment.

The ballistic performance was reconstructed using SCB04 steady state 1-D mass addition computer program, and SCA08 SRM modeling program. Both computer codes have been consistently used for predictions as well as reconstructions throughout the SRM program. Since thrust was not measured on the flight motors, average values of η_r's and C_m's, which are used for the pressure to thrust conversion, were taken from RSRM static test motors and applied to the measured head end pressure to determine the thrust values. The average thrust to pressure ratio currently used is 3916.

3.3 RSRM DELIVERED PERFORMANCE

3.3.1 RSRM-11A/RSRM-11B Thrust and Pressure Comparison

The flight motor reconstructed thrust-time traces at the delivered temperature of 73°F are shown in Figure 2.1. A comparison between the predicted thrust and reconstructed thrust for each motor can be seen in Figures 3.1 and 3.2.

The comparison of predicted and measured head end chamber pressure is shown in Figures 3.3 and 3.4.

Figures 3.5 and 3.6 show how RSRM-11A and RSRM-11B compared with a nominal performance average for the RSRM at standard conditions of 0.368 burn rate and 60 °F PMBT. The thrust limits shown in the figures have recently been updated and approved by Level II and incorporated into the CEI specification. The population of motors used to determine the thrust limits were the RSRM motors DM-8, DM-9, QM-6, QM-7, PVM-1, QM-8 and RSRM-1 through RSRM-4.

3.3.2 RSRM Predicted Impulse, ISP, Burn Rate, Event Times, Separation, and PMBT Comparison

The reconstructed RSRM-11 propulsion performance at delivered conditions is compared to the predicted performance in Table 3.2. Both motors are in good agreement with the predicted parameters.

The predicted scale factor of 1.0175 for conversions from 5 inch CP burn rates to actual motor burn rate were based on an average scale factor from the HPM-RSRM population. The actual scale factors for left and right motors were 1.0127 and 1.0094 respectively.

The propellant mean bulk temperature (PMBT) used in the Ballistics reconstruction for both motors was 73°F. This was predicted using the 3-D Global Thermal Model. Table 3.3 shows the predicted propellant temperature gradient (data provided by 2-D SINDA Model Aerothermal Group).

3.4 CEI SPECIFICATION PERFORMANCE REQUIREMENTS

3.4.1 Performance Tolerances

The parameter variations of the total population of RSRMs about a nominal value are constrained by the requirements defined in the CEI Specification paragraph 3.2.1.1.2.2, Table II. A comparison of the RSRM-11A and RSRM-11B calculated and reconstructed parameters at PMBT of 60°F with respect to the nominal values and the CEI Specification maximum 3 sigma requirements is shown in Tables 3.4 and 3.5. The Specification Limits have been updated to the new limits approved by Level II. All values are within CEI specification requirements.

3.4.2 RSRM Nominal Thrust-Time Performance

The nominal RSRM performance is defined as the average performance of the RSRM static test and flight motor series at standard conditions. The standard conditions consist of the propellant burn rate of 0.368 in/sec at 625 psia and a PMBT of 60°F. The flight motor reconstructed thrust-time traces are normalized to standard conditions and averaged with past flight and static test data at standard conditions to form the RSRM population nominal thrust-time trace. This nominal RSRM performance

will be continually updated during the Shuttle program. It is the current estimate of the total population nominal. The nominal performance for the thrust time trace and impulse gate requirements is based on the performance of DM-8, DM-9, QM-6, QM-7, PVM-1 and RSRM-1 through RSRM-4A, excluding RSRM-4B. The delivered RSRM population nominal performance is compared to the CEI Specification paragraph 3.2.1.1.2.1, Table I requirements on Figure 3.7.

3.4.3 Impulse at Standard Conditions VS. Requirement Gates

The vacuum impulse at standard conditions at each of the gates is compared to the CEI Specification paragraph 3.2.1.1.2.4 requirements in Table 3.6. The population making up the standard nominal for the impulse requirements are the same as those in the nominal thrust time trace (Figure 3.7).

3.4.4 Matched Pair Thrust Differential

The maximum thrust imbalance assessment is shown in Table 3.7. Figure 3.8 is the thrust differential during steady state and tail off. The transition thrust imbalance was one of the higher values experienced by the RSRM. The mismatched aft segment may have caused the higher thrust imbalance. However, the maximum value of 65.6 Klbf was well within the CEI specification limits. All other thrust differential values were near the nominal values experienced by previous flight SRMs and were well within the CEI Specification paragraph 3.2.1.1.2.3, Table III limits. The thrust values used for the assessment were reconstructed at the delivered conditions of each motor.

3.4.5 Matched Pair Performance Requirements

The CEI Specification requires that a matched pair of motors on a flight set have similar performance at delivered conditions according to Table 3.8. The RSRMs for STS-35 were well within the matched pair specification requirements.

3.5 RECONSTRUCTED MASS PROPERTIES

The Thiokol manufacturing designation, 360W011, along with RSRM-11 have been used, by Mass Properties, to identify the RSRMs used on this flight. The left and right hand RSRMs for the flight will be designated as A and B. Tables 3.9 and 3.10 provide RSRM-11A and RSRM-11B reconstructed sequential mass properties, respectively.

Table 3.11 and 3.12 compares RSRMW predicted sequential weight and center of gravity (cg) data against post flight reconstructed data. A 2,000 lbm slag weight was used for both prefire and postfire sequential predictions. Actual 360W011 mass properties may be obtained from Mass Properties History Log Space Shuttle 360W011-LH (TWR-17354A), dated 16 February 1990, and 360W011-RH (TWR-17355A), dated 16 February 1990. Some of the mass properties data used has been taken from average actual data presented in the 5 December 1990 Mass Properties Quarterly Status Report (TWR-10211-97). Postflight reconstructed data reflects Ballistics mass flow data from the 12.5 sample per second measured pressure traces and a predicted slag weight of 2,000 lbm.

Table 3.13 and 3.14 presents CEI requirements, predicted, and actual weight comparisons. The actual weights are in close agreement with predicted values. Mass Properties data for both RSRMs comply with CEI requirements.

TABLE 3.1
RAW MATERIAL EVALUATION SUMMARY

TP-H1148 PROPELLANT EVALUATION	INGREDIENT	STOCK-LOT	VENDOR
F68	HB Polymer	7227-0076	ASRC
	ECA	7225-0085	Dow Chemical
	Aluminum	7228-0073	Alcan
	Iron Oxide	7226-0026	Charles Pfizer
	AP unground	7229-0088	Kerr McGee
	AP ground	7229-0088	Kerr McGee
	HB/ECA Ratio	86.6% HB	
	Iron Oxide	0.324%	
F72V	HB Polymer	7227-0077	ASRC
	ECA	7225-0090	Dow Chemical
	Aluminum	7228-0078	Reynolds
	Iron Oxide	7226-0026	Charles Pfizer
	AP unground	7229-0092	Kerr McGee
	AP ground	7229-0092	Kerr McGee
	HB/ECA Ratio	86.3% HB	
	Iron Oxide	0.260%	
F67	HB Polymer	7227-0075	ASRC
	ECA	7225-0083	Dow Chemical
	Aluminum	7228-0072	Reynolds
	Iron Oxide	7226-0026	Charles Pfizer
	AP unground	7229-0087	Kerr McGee
	AP ground	7229-0087	Kerr McGee
	HB/ECA Ratio	86.9% HB	
	Iron Oxide	0.26%	

TABLE 3.2 RSRM-11 PROPULSION PERFORMANCE ASSESSMENT

	(LEFT MOTOR 73 DEG) PREDICTED	ACTUAL	(RIGHT MOTOR 73 DEG) PREDICTED	ACTUAL
IMPULSE GATES				
I-20 (10^6 lbf sec)	65.83	65.36	66.04	65.67
I-60 (10^6 lbf sec)	175.38	173.76	175.93	174.48
I-AT (10^6 lbf sec)	297.22	296.14	297.19	296.57
VACUUM ISP (lbf*sec/lbm)	268.6	267.6	268.6	268.0
BURN RATE (in/sec)	0.371	0.3700	0.372	0.3698
EVENT TIMES (sec) *				
IGNITION INTERVAL	0.232	N/A	0.232	N/A
WEB TIME *	109.6	110.3	109.2	110.1
TIME OF 50 PSIA CUE	119.4	120.4	119.4	120.5
ACTION TIME *	121.5	122.6	121.0	122.6
SEPARATION COMMAND (sec)	124.3	125.8	124.3	125.8
PMBT (deg F)	73.0	73.0	73.0	73.0
MAXIMUM IGNITION RISE RATE (psia/10 ms)	90.4	N/A	90.4	N/A
DECAY TIME (sec) (59.4 psia to 85 K)	2.8	3.1	2.8	2.8
TAILOFF IMBALANCE IMPULSE DIFFERENTIAL (KLBF-SEC)	PREDICTED N/A		ACTUAL 333.2	

Impulse Imbalance = Left Motor - Right Motor

* All times are referenced to ignition command time except where noted by an *. These times are referenced to lift off time (ignition interval).

TABLE 3.3

PREDICTED PROPELLANT TEMPERATURE GRADIENTS AT IGNITION IN RSRM-11

DISTANCE FROM OUTSIDE SURFACE OF CASE (IN.)		15	45	75	105	135	165	195	225	255	285	315	345
0.0	CASE SURFACE	70.74	70.74	70.76	70.81	71.03	71.37	71.68	71.86	71.87	71.67	71.24	70.88
0.25	STEEL CASE	70.74	70.74	70.77	70.81	71.04	71.38	71.69	71.86	71.87	71.67	71.24	70.89
1.904	PROPELLANT	70.71	70.71	70.75	70.84	71.07	71.41	71.68	71.84	71.84	71.64	71.21	70.86
6.114	"	70.46	70.46	70.54	70.68	70.92	71.24	71.49	71.64	71.64	71.43	70.99	70.62
13.130	"	71.13	71.11	71.21	71.39	71.63	71.95	72.18	72.33	72.33	72.12	71.68	71.31
21.550	"	71.45	71.41	71.50	71.69	71.93	72.24	72.48	72.64	72.63	72.43	72.00	71.63
29.970	"	71.69	71.64	71.71	71.91	72.16	72.46	72.68	72.85	72.84	72.63	72.24	71.88
38.390	"	71.92	71.86	71.93	72.12	72.37	72.65	72.89	73.05	73.04	72.83	72.46	72.11

TABLE 3.4

COMPARISON OF RSRM-11A VARIATIONS AT PMBT = 60°F ABOUT THE NOMINAL TO THE CEI SPECIFICATION REQUIREMENTS

PARAMETER	CEI MAX 3 SIGMA VARIATION% (1)	NOMINAL VALUE (2)	RSRM-11A VALUE (3)	RSRM-11A VARIATION % (4)
WEB TIME	±5.0	111.1	111.8	+0.60
ACTION TIME	±6.5	123.2	124.3	+0.89
WEB TIME AVG PRESSURE	±5.3	664.8	658.5	-0.95
MAX PRESSURE	±6.5	914.2	913.7	-0.05
MAX SEA LEVEL THRUST	±6.2	3.07	3.05	-0.65
WEB TIME AVG VAC THRUST	±5.3	2.60	2.58	-0.77
VAC DEL SPECIFIC IMPULSE	±0.7	268.4	267.5	-0.34
WEB TIME VAC TOTAL IMPULSE	±1.0	288.2	288.0	-0.07
ACTION TIME TOTAL IMPULSE	±1.0	296.9	295.8	-0.37

PRESSURE VALUES IN PSIA, THRUST VALUES IN MLBF,
IMPULSE VALUES IN MLBF-SEC
TIME VALUES IN SECONDS

(1) CEI PARAGRAPH 3.2.1.1.2.2, TABLE II

(2) QM-4 STATIC TEST AND SRM-8A AND B, SRM-9A, SRM-10A, SRM-10B, SRM-11A, SRM-13A AND SRM-13B FLIGHT AVERAGE AT STANDARD CONDITIONS.

(3) RSRM-11A AT PMBT = 60°F

(4) VARIATION = ((RSRM-11A - NOMINAL)/NOMINAL)*100

TABLE 3.5

COMPARISON OF RSRM-11B VARIATIONS AT PMBT = 60°F ABOUT THE NOMINAL TO THE CEI SPECIFICATION REQUIREMENTS

PARAMETER	CEI MAX 3 SIGMA VARIATION% (1)	NOMINAL VALUE (2)	RSRM-11B VALUE (3)	RSRM-11B VARIATION % (4)
WEB TIME	±5.0	111.1	111.5	+0.36
ACTION TIME	±6.5	123.2	124.3	+0.89
WEB TIME AVG PRESSURE	±5.3	664.8	660.1	-0.71
MAX PRESSURE	±6.5	914.2	916.9	+0.30
MAX SEA LEVEL THRUST	±6.2	3.07	3.06	-0.33
WEB TIME AVG VAC THRUST	±5.3	2.60	2.58	-0.77
VAC DEL SPECIFIC IMPULSE	±0.7	268.4	267.8	-0.22
WEB TIME VAC TOTAL IMPULSE	±1.0	288.2	288.0	-0.07
ACTION TIME TOTAL IMPULSE	±1.0	296.9	296.2	-0.24

PRESSURE VALUES IN PSIA, THRUST VALUES IN MLBF,
IMPULSE VALUES IN MLBF-SEC
TIME VALUES IN SECONDS

(1) CEI PARAGRAPH 3.2.1.1.1, TABLE II

(2) QM-4 STATIC TEST AND SRM-8A AND B, SRM-9A, SRM-10A, SRM-10B, SRM-11A, SRM-13A AND SRM-13B FLIGHT AVERAGE AT STANDARD CONDITIONS.

(3) RSRM-11B AT PMBT = 60 F

(4) VARIATION = ((RSRM-11B - NOMINAL)/NOMINAL)*100

TABLE 3.6

RSRM-HPM POPULATION IMPULSE GATES

IMPULSE (3)	REQUIREMENT (1)	STANDARD NOMINAL (2)
Impulse at 20 sec (10**6 LBF-SEC)	63.1 (MIN)	64.8
Impulse at 60 sec (10**6 LBF-SEC)	171.2 - 178.1 172.9 (+3%,-1%)	173.0
Impulse at ACTION TIME (10**6 LBF-SEC)	293.8 (MIN)	296.8

(1) CEI PARAGRAPH 3.2.1.1.2.4

(2) NORMALIZED TO STANDARD CONDITIONS-BURN RATE OF 0.368 IN/SEC. POPULATION IS SAME AS USED TO COMPARE NOMINAL THRUST TRACE, Figure 3.7.

(3) IMPULSE VALUES ARE CALCULATED FROM IGNITION.

TABLE 3.7 RSRM-11 THRUST IMBALANCE SUMMARY

EVENT	IMBALANCE SPECIFICATION (KLBF)	MAXIMUM IMBALANCE (KLBF)	TIME OF MAXIMUM IMBALANCE (SEC)
STEADY STATE (1) (1 TO 79 SEC.)	85	- 26.5	66.5
STEADY STATE (2) (79 SEC TO FIRST WEB TIME MINUS 8.5 SEC.)	120	+ 41.6	101.5
TRANSITION (FIRST WEB TIME MINUS 8.5 SEC TO FIRST WEB TIME, LBF)	120 - 268 LINEAR	+65.6	103.0
TAILOFF (FIRST WEB TIME TO LAST ACTION TIME)	710	+ 37.0	110.5

THRUST IMBALANCE = LEFT SRM - RIGHT SRM

TABLE 3.8
MATCHED PAIR PERFORMANCE LIMITS

PARAMETER	CEI SPECIFICATION MAX DIFFERENCE (%) (1)	DELIVERED % DIFFERENCE (2)
WEB TIME	±2.0	+0.27
ACTION TIME	±3.0	+0.00
WEB TIME AVG PRESSURE	±2.0	-0.24
MAX PRESSURE	N/A	-0.35
MAX SEA LEVEL THRUST	N/A	-0.33
WEB TIME AVG VAC THRUST	±2.0	+0.00
VAC DEL SPECIFIC IMPULSE	±1.0	-0.11
WEB TIME VAC TOTAL IMPULSE	±1.4	-0.00
ACTION TIME TOTAL IMPULSE	±1.4	-0.14

PRESSURE VALUES IN PSIA, THRUST VALUES IN MLBF,
IMPULSE VALUES IN MLBF-SEC
TIME VALUES IN SECONDS

(1) CEI SPECIFICATION PARAGRAPH 3.2.1.1.2.2, TABLE II

(2) DIFFERENCE = ((RSRM-11A - RSRM-11B)/RSRM-11 AVERAGE)*100
DATA AT PMBT OF 73 °F

TABLE 3.9

RSRM-11A SEQUENTIAL MASS PROPERTIES

EVENTS/TIMES	WEIGHT (LBS)	CENTER OF GRAVITY LONG.	LAT.	VERT.	MOMENT OFINERTIA PITCH	ROLL	YAW
PRE-LAUNCH TIME = 0.00	1256296.4	1171.312	0.059	0.006	42462.594	879.740	42463.471
LIFT-OFF TIME = 0.23	1255600.3	1171.444	0.059	0.006	42419.697	878.417	42420.574
INTERMEDIATE BURN TIME = 20.00	1012744.6	1208.422	0.073	0.008	30683.272	760.770	30684.147
INTERMEDIATE BURN TIME = 40.00	791738.1	1231.611	0.093	0.010	21678.413	626.029	21679.282
MAX "Q" TIME = 54.00	661779.8	1229.172	0.111	0.012	17996.876	548.560	17997.738
INTERMEDIATE BURN TIME = 60.00	607032.9	1226.629	0.121	0.013	16589.783	511.943	16590.642
INTERMEDIATE BURN TIME = 80.00	414820.7	1214.879	0.175	0.018	11911.688	377.831	11912.535
MAX "G" TIME = 87.00	350807.1	1214.119	0.206	0.022	10530.330	327.232	10531.173
INTERMEDIATE BURN TIME = 100.00	245147.2	1227.449	0.293	0.031	8529.886	238.130	8530.721
WEB BURN TIME = 110.48	174256.5	1266.891	0.410	0.044	7312.881	173.096	7313.709
END OF ACTION TIME TIME = 122.86	144363.6	1316.924	0.493	0.053	6584.511	146.528	6585.334
SEPARATION TIME = 125.40	143742.3	1319.134	0.496	0.053	6543.057	146.182	6543.883
MAX REENTRY "Q" TIME = 320.40	143306.0	1319.207	0.496	0.052	6522.547	145.818	6523.374
NOSE CAP DEPLOYMENT TIME = 350.40	143253.8	1319.189	0.497	0.052	6519.788	145.772	6520.615
DROGUE CHUTE DEPLOYMENT TIME = 351.00	143252.8	1319.189	0.497	0.052	6519.733	145.771	6520.559
FRUSTUM RELEASE TIME = 372.10	143216.1	1319.176	0.497	0.052	6517.779	145.738	6518.607
MAIN CHUTE LINE STRETCH TIME = 373.40	143213.9	1319.176	0.497	0.052	6517.659	145.736	6518.486
MAIN CHUTE 1ST DISREEFING TIME = 383.50	143196.3	1319.170	0.497	0.052	6516.720	145.721	6517.547
MAIN CHUTE 2ND DISREEFING TIME = 389.40	143186.0	1319.166	0.497	0.052	6516.171	145.712	6516.998
NOZZLE JETTISONED TIME = 390.10	140958.0	1309.019	0.496	0.052	6317.733	141.119	6318.538
SPLASHDOWN TIME = 415.40	140914.0	1309.002	0.496	0.052	6315.358	141.080	6316.165

TABLE 3.10

RSRM-11B SEQUENTIAL MASS PROPERTIES

EVENTS/TIMES	WEIGHT (LBS)	CENTER OF GRAVITY LONG.	LAT.	VERT.	MOMENT OFINERTIA PITCH	ROLL	YAW
PRE-LAUNCH TIME = 0.00	1256359.8	1171.651	0.059	0.006	42463.573	879.936	42464.448
LIFT-OFF TIME = 0.23	1255662.9	1171.782	0.059	0.006	42420.363	878.626	42421.238
INTERMEDIATE BURN TIME = 20.00	1012058.7	1208.905	0.074	0.008	30641.991	760.398	30642.864
INTERMEDIATE BURN TIME = 40.00	790658.6	1232.048	0.094	0.010	21637.661	625.507	21638.528
MAX "Q" TIME = 54.00	660417.6	1229.535	0.111	0.012	17964.368	548.136	17965.227
INTERMEDIATE BURN TIME = 60.00	605384.3	1226.978	0.121	0.013	16549.556	511.145	16550.413
INTERMEDIATE BURN TIME = 80.00	412483.1	1215.363	0.176	0.018	11861.446	376.505	11862.291
MAX "G" TIME = 87.00	348897.3	1214.841	0.207	0.022	10492.880	326.184	10493.722
INTERMEDIATE BURN TIME = 100.00	243827.3	1228.666	0.295	0.031	8504.509	237.474	8505.341
WEB BURN TIME = 110.29	175485.1	1266.628	0.407	0.043	7329.601	174.764	7330.427
END OF ACTION TIME TIME = 122.84	144509.5	1316.055	0.493	0.053	6598.865	146.873	6599.686
SEPARATION TIME = 125.40	143867.0	1317.671	0.496	0.053	6569.668	146.402	6570.492
MAX REENTRY "Q" TIME = 320.40	143428.7	1317.689	0.496	0.052	6548.474	146.013	6549.299
NOSE CAP DEPLOYMENT TIME = 350.40	143376.6	1317.670	0.497	0.052	6545.714	145.967	6546.539
DROGUE CHUTE DEPLOYMENT TIME = 351.00	143375.5	1317.670	0.497	0.052	6545.658	145.966	6546.483
FRUSTUM RELEASE TIME = 372.10	143338.8	1317.657	0.497	0.052	6543.704	145.934	6544.529
MAIN CHUTE LINE STRETCH TIME = 373.40	143336.6	1317.656	0.497	0.052	6543.584	145.932	6544.408
MAIN CHUTE 1ST DISREEFING TIME = 383.50	143319.0	1317.650	0.497	0.052	6542.644	145.916	6543.469
MAIN CHUTE 2ND DISREEFING TIME = 389.40	143308.8	1317.647	0.497	0.052	6542.095	145.907	6542.920
NOZZLE JETTISONED TIME = 390.10	141078.6	1307.483	0.495	0.052	6342.533	141.318	6343.339
SPLASHDOWN TIME = 415.40	141034.6	1307.466	0.495	0.052	6340.159	141.279	6340.964

TABLE 3.11

SEQUENTIAL MASS PROPERTIES PREDICTED/ACTUAL COMPARISONS
360W011 Left Hand

Event	Weight (lb)				Longitudinal CG (in)			
	Predicted[1]	Actual	Delta	% Error	Predicted[1]	Actual	Delta	% Error
Pre-Ignition	1,256,296	1,256,296	0	0.00	1,171.312	1,171.312	0.000	0.00
Liftoff	1,255,604	1,255,600	-4	0.00	1,171.444	1,171.444	0.000	0.00
Action Time	144,275	144,364	+89	0.06	1,317.643	1,316.924	-0.719	0.05
Separation[2]	143,744	143,742	-2	0.00	1,319.256	1,319.134	-0.122	0.01
Nose Cap Deployment	143,255	143,254	-1	0.00	1,319.206	1,319.189	-0.017	0.00
Drogue Chute Deployment	143,254	143,253	-1	0.00	1,319.205	1,319.189	-0.016	0.00
Main Chute Line Stretch	143,215	143,214	-1	0.00	1,319.192	1,319.176	-0.016	0.00
Main Chute 1st Disreefing	143,197	143,196	-1	0.00	1,319.186	1,319.170	-0.016	0.00
Main Chute 2nd Disreefing	143,187	143,186	-1	0.00	1,319.183	1,319.166	-0.017	0.00
Nozzle Jettison	140,958	140,958	0	0.00	1,309.019	1,309.019	0.000	0.00
Splash Down	140,914	140,914	0	0.00	1,309.002	1,309.002	0.000	0.00

Notes:

1. Based on Mass Properties History Log Space Shuttle 360W011-LH, 16 February 1990 (TWR-17354A).

2. The separation longitudinal center of gravity of 1,319.134 is 66% of the vehicle length.

TABLE 3.12

SEQUENTIAL MASS PROPERTIES PREDICTED/ACTUAL COMPARISONS
360W011 Right Hand

Event	Weight (lb)				Longitudinal CG (in)			
	Predicted[1]	Actual	Delta	% Error	Predicted[1]	Actual	Delta	% Error
Pre-Ignition	1,256,360	1,256,360	0	0.00	1,171.651	1,171.651	0.000	0.00
Liftoff	1,255,668	1,255,663	-5	0.00	1,171.783	1,171.782	-0.001	0.00
Action Time	144,395	144,509	+114	0.08	1,316.141	1,316.055	-0.086	0.01
Separation[2]	143,865	143,867	+2	0.00	1,317.744	1,317.671	-0.073	0.01
Nose Cap Deployment	143,376	143,377	+1	0.00	1,317.689	1,317.670	-0.019	0.00
Drogue Chute Deployment	143,375	143,376	+1	0.00	1,317.688	1,317.670	-0.018	0.00
Main Chute Line Stretch	143,336	143,337	+1	0.00	1,317.675	1,317.656	-0.019	0.00
Main Chute 1st Disreefing	143,318	143,319	+1	0.00	1,317.669	1,317.650	-0.019	0.00
Main Chute 2nd Disreefing	143,308	143,309	+1	0.00	1,317.666	1,317.647	-0.019	0.00
Nozzle Jettison	141,078	141,078	0	0.00	1,307.484	1,307.483	-0.001	0.00
Splash Down	141,035	141,035	0	0.00	1,307.466	1,307.466	0.000	0.00

Notes:

1. Based on Mass Properties History Log Space Shuttle 360W011-RH, 16 February 1990 (TWR-17355A).

2. The separation longitudinal center of gravity of 1,317.671 is 66% of the vehicle length.

TABLE 3.13

PREDICTED/ACTUAL WEIGHT (lb) COMPARISONS

360W011 LEFT HAND

Item	Minimum	Maximum	Predicted[3]	Actual	Delta	% Error	Notes
Inerts							
Prefire, Controlled		151,490	149,524	149,524	0	0.00	1
Propellant	1,103,690		1,106,773	1,106,773	0	0.00	1
Usable			1,105,857	1,106,120	+263	0.02	2
To Liftoff			592	596	+4	0.67	
Liftoff to Action			1,105,265	1,105,524	+259	0.02	2
Unusable			916	653	-263	40.28	
Action to Separation			818	556	-262	47.12	
After Separation			98	97	-1	1.03	
Slag			2,000	2,000	0	0.00	2

Notes:

1. Requirement per CPW1-3600A, Addendum G, Part I, (RSRM CEI Specification).
2. Slag included in usable propellant, liftoff to action.
3. Based on 16 February 1990, Mass Properties History Log Space Shuttle 360W011-LH (TWR-17354A).

TABLE 3.14

PREDICTED/ACTUAL WEIGHT (lb) COMPARISONS

360W011 RIGHT HAND

Item	Minimum	Maximum	Predicted[3]	Actual	Delta	% Error	Notes
Inerts							
Prefire, Controlled		151,490	149,648	149,648	0	0.00	1
Propellant	1,103,690		1,106,712	1,107,712	0	0.00	1
Usable			1,105,797	1,106,036	+239	0.02	2
To Liftoff			592	597	+5	0.84	
Liftoff to Action			1,105,205	1,105,439	+234	0.02	2
Unusable			915	676	-239	35.36	
Action to Separation			817	577	-240	41.59	
After Separation			98	99	+1	1.01	
Slag			2,000	2,000	0	0.00	2

Notes:

1. Requirement per CPW1-3600A, Addendum G, Part I, (RSRM CEI Specification).
2. Slag included in usable propellant, liftoff to action.
3. Based on 16 February 1990, Mass Properties History Log Space Shuttle 360W011-RH (TWR-17355A).

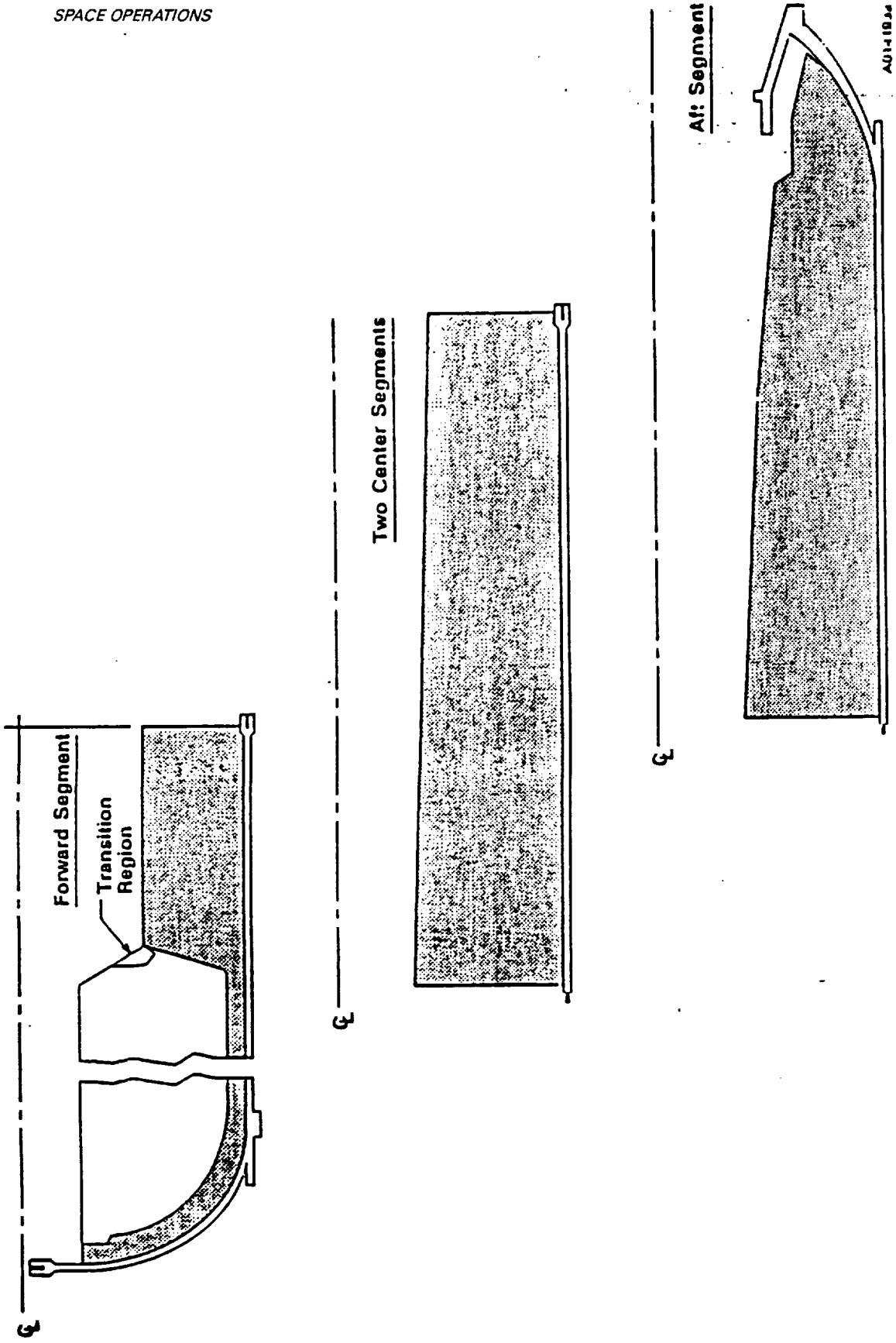

Figure 1.1 RSRM Propellant Grain Design Configuration

FIGURE 2.1
RSRM-11 RECONSTRUCTED VACUUM THRUST VS. TIME
AT DELIVERED CONDITIONS (73 deg F)

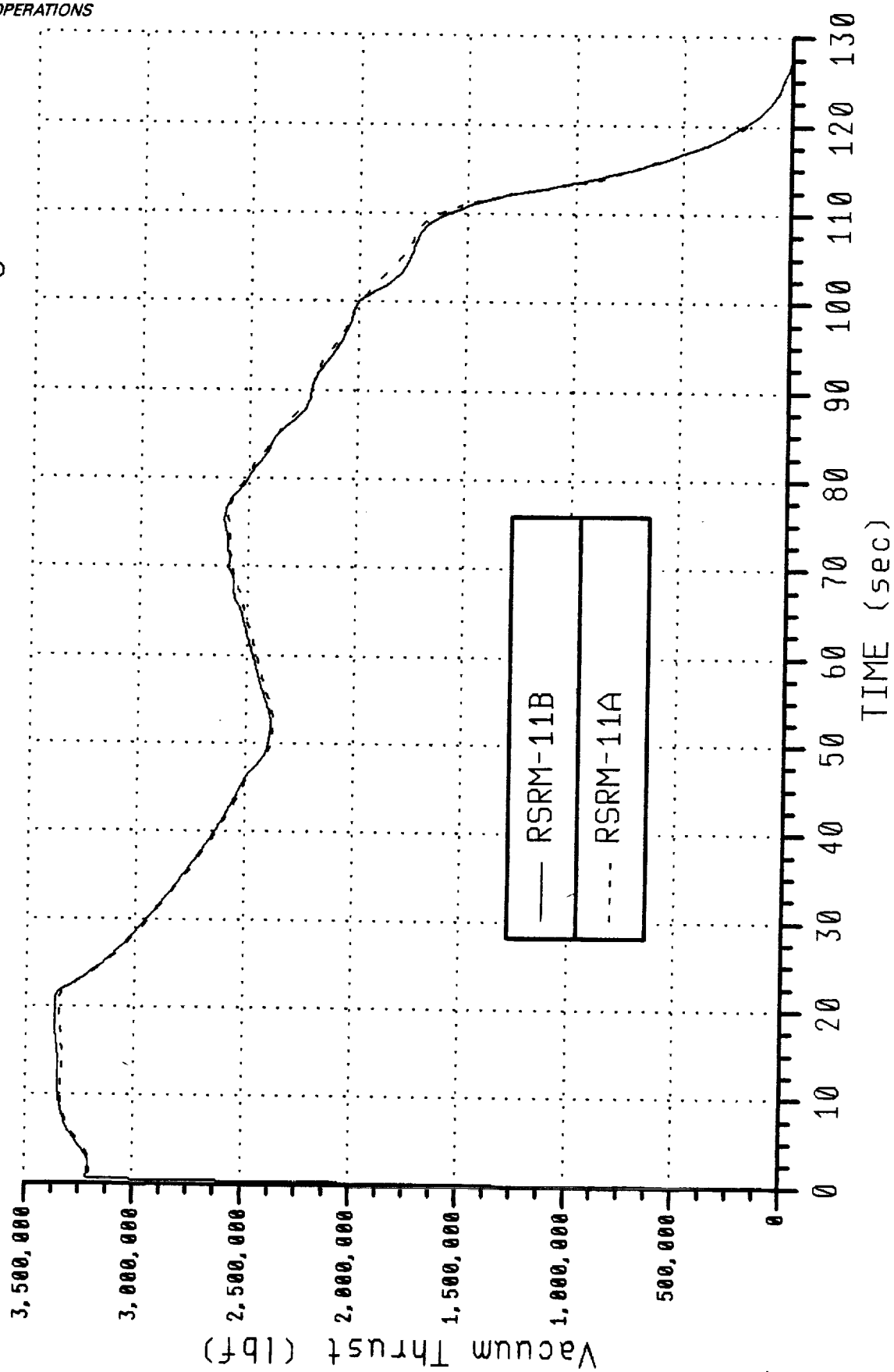

FIGURE 3.1
RSRM-11A PREDICTED VS. RECONSTRUCTED
VACUUM THRUST

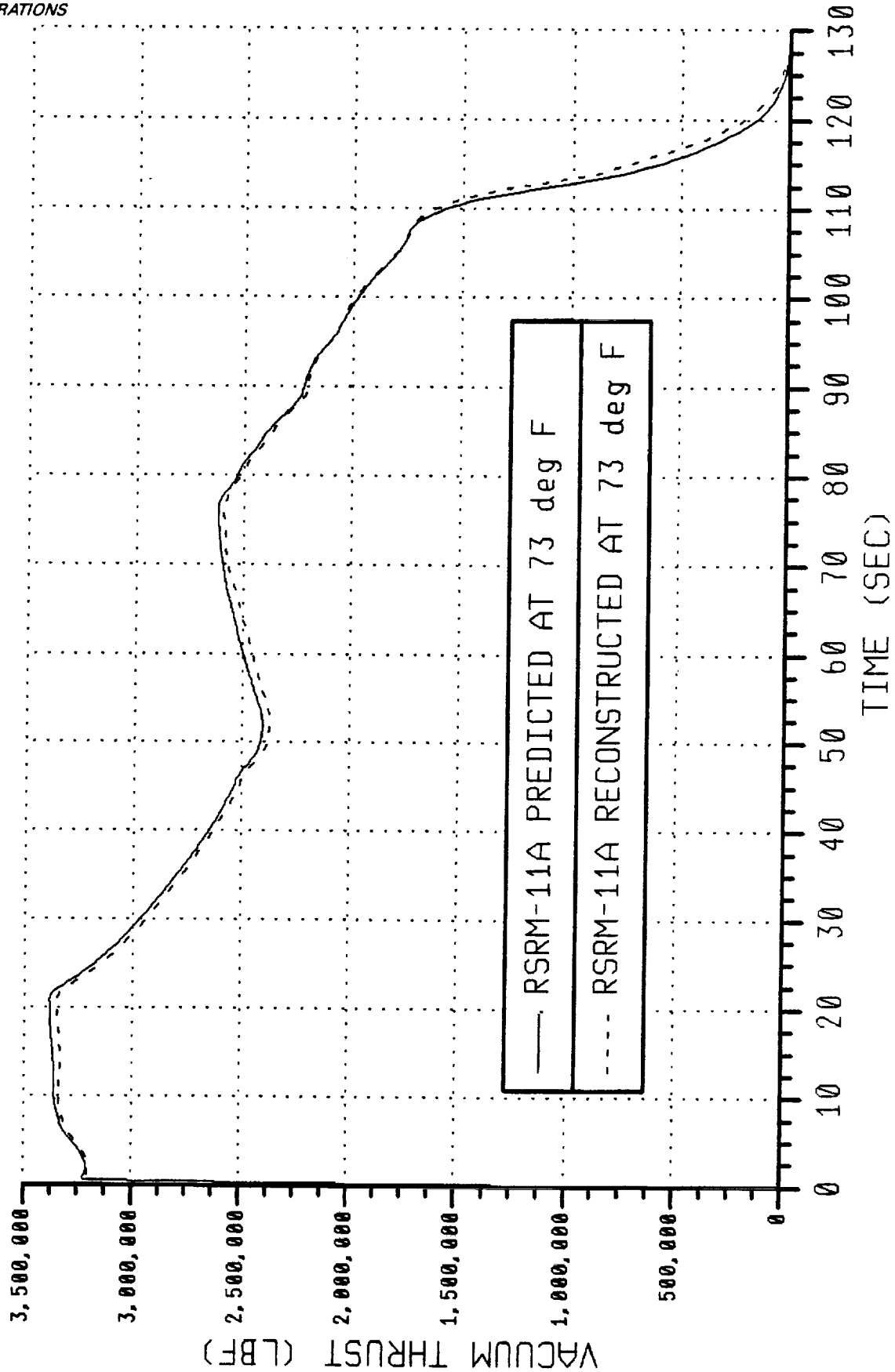

FIGURE 3.2
RSRM-11B PREDICTED VS. RECONSTRUCTED
VACUUM THRUST

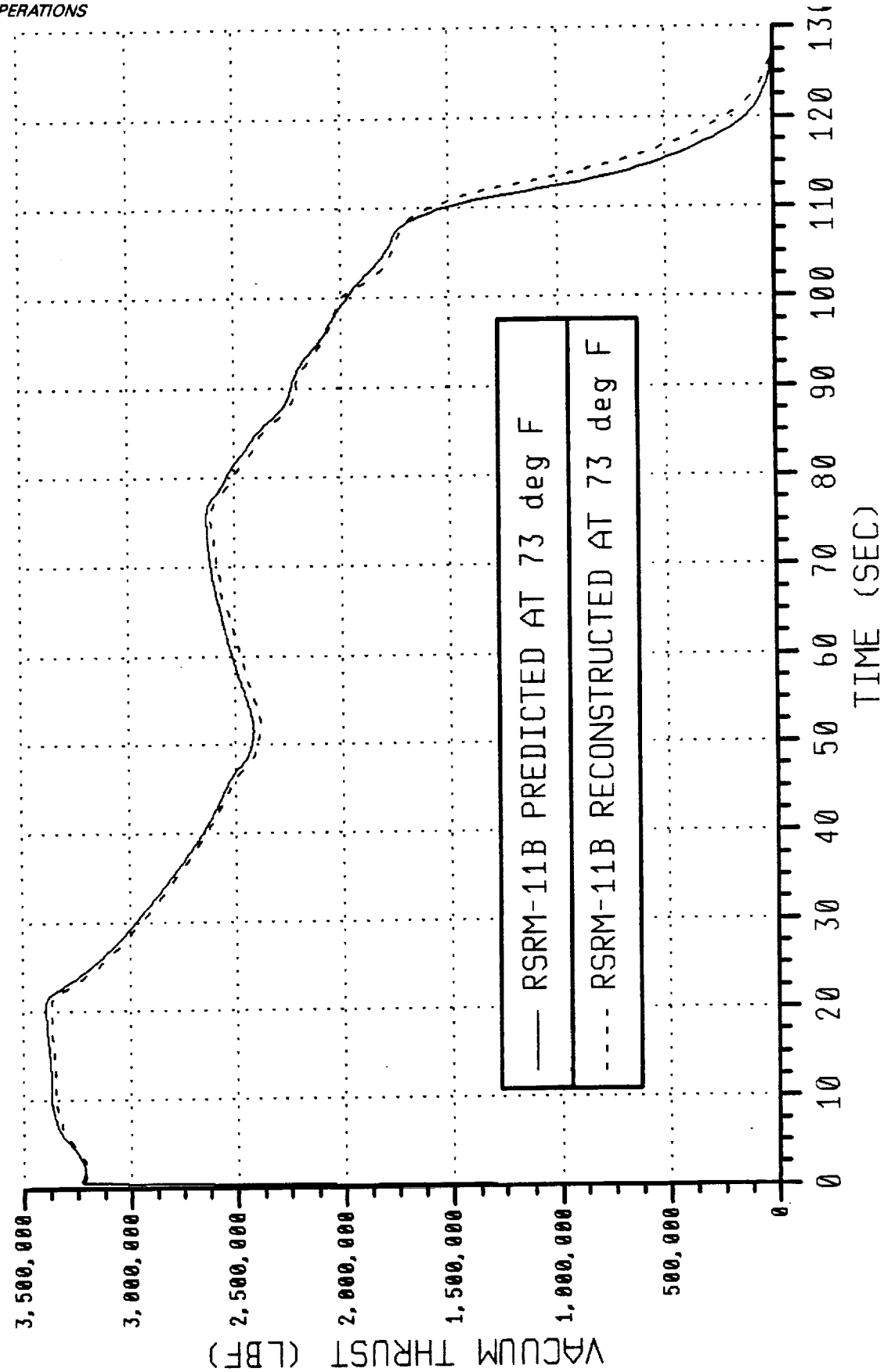

FIGURE 3.3
RSRM-11A PREDICTED VS. MEASURED
CHAMBER PRESSURE

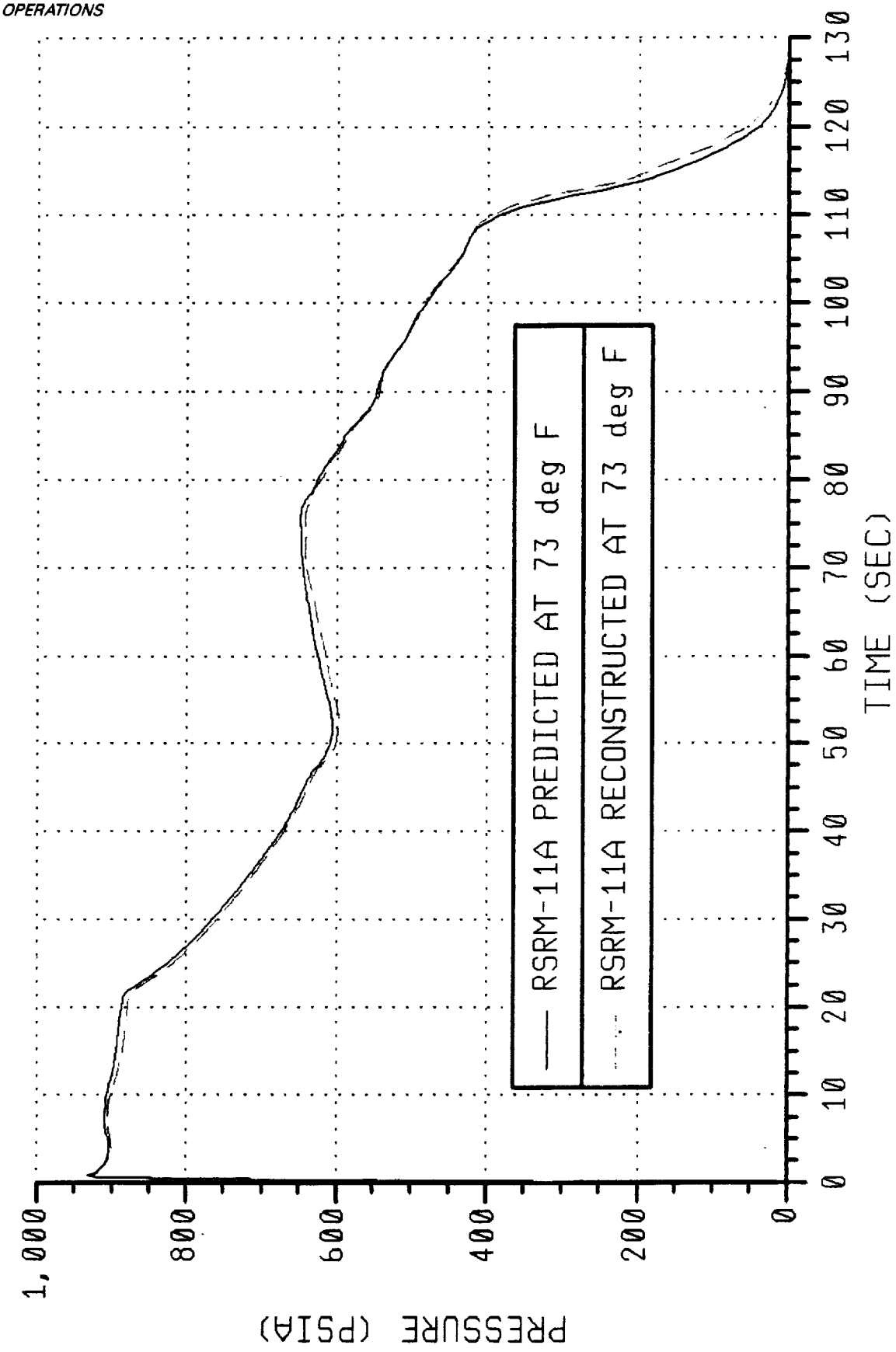

FIGURE 3.4
RSRM-11B PREDICTED VS. MEASURED
CHAMBER PRESSURE

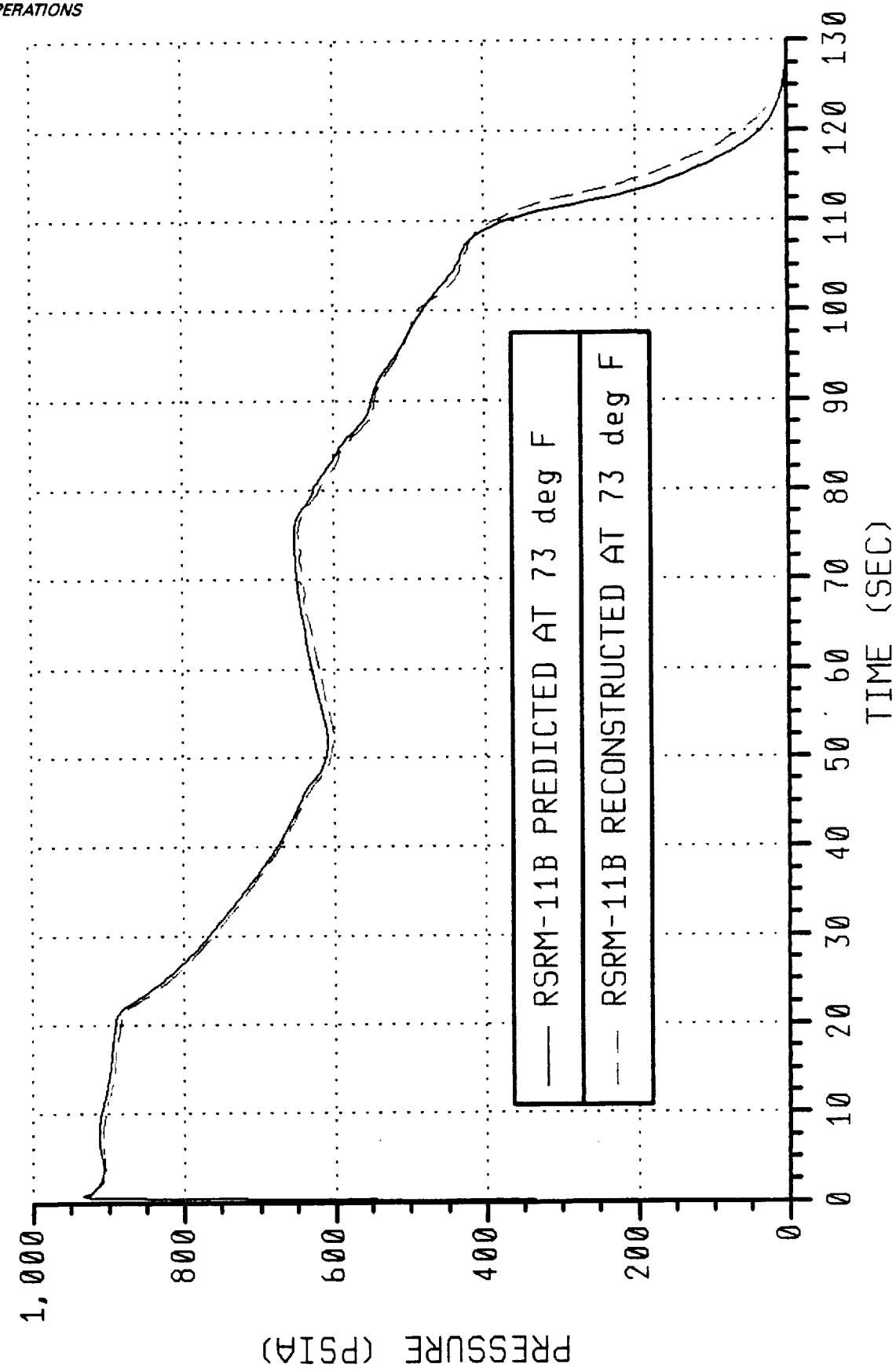

FIGURE 3.5
RSRM-11A PERFORMANCE COMPARED TO
RSRM POPULATION NOMINAL

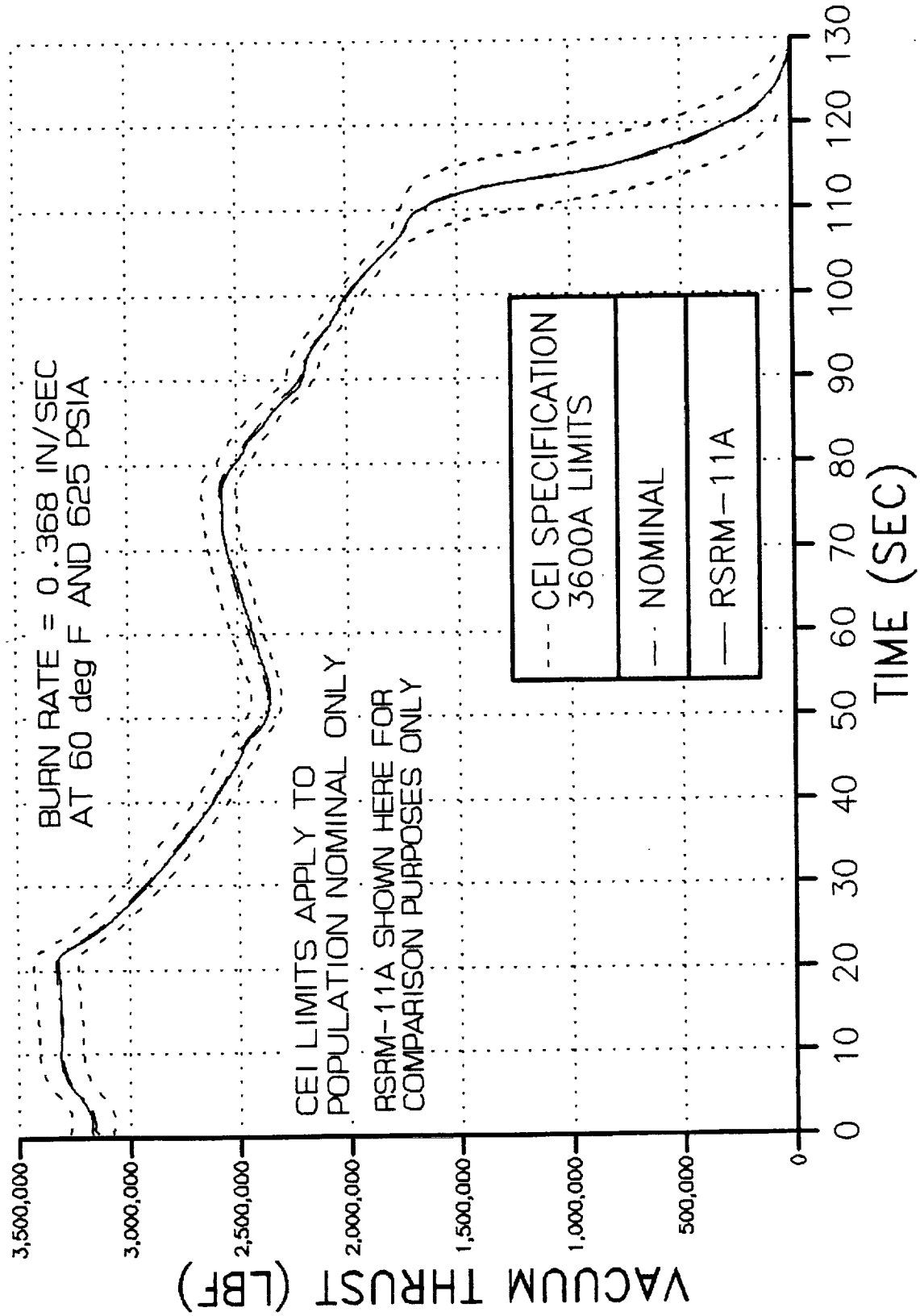

FIGURE 3.6
RSRM-11B PERFORMANCE COMPARED TO
RSRM POPULATION NOMINAL

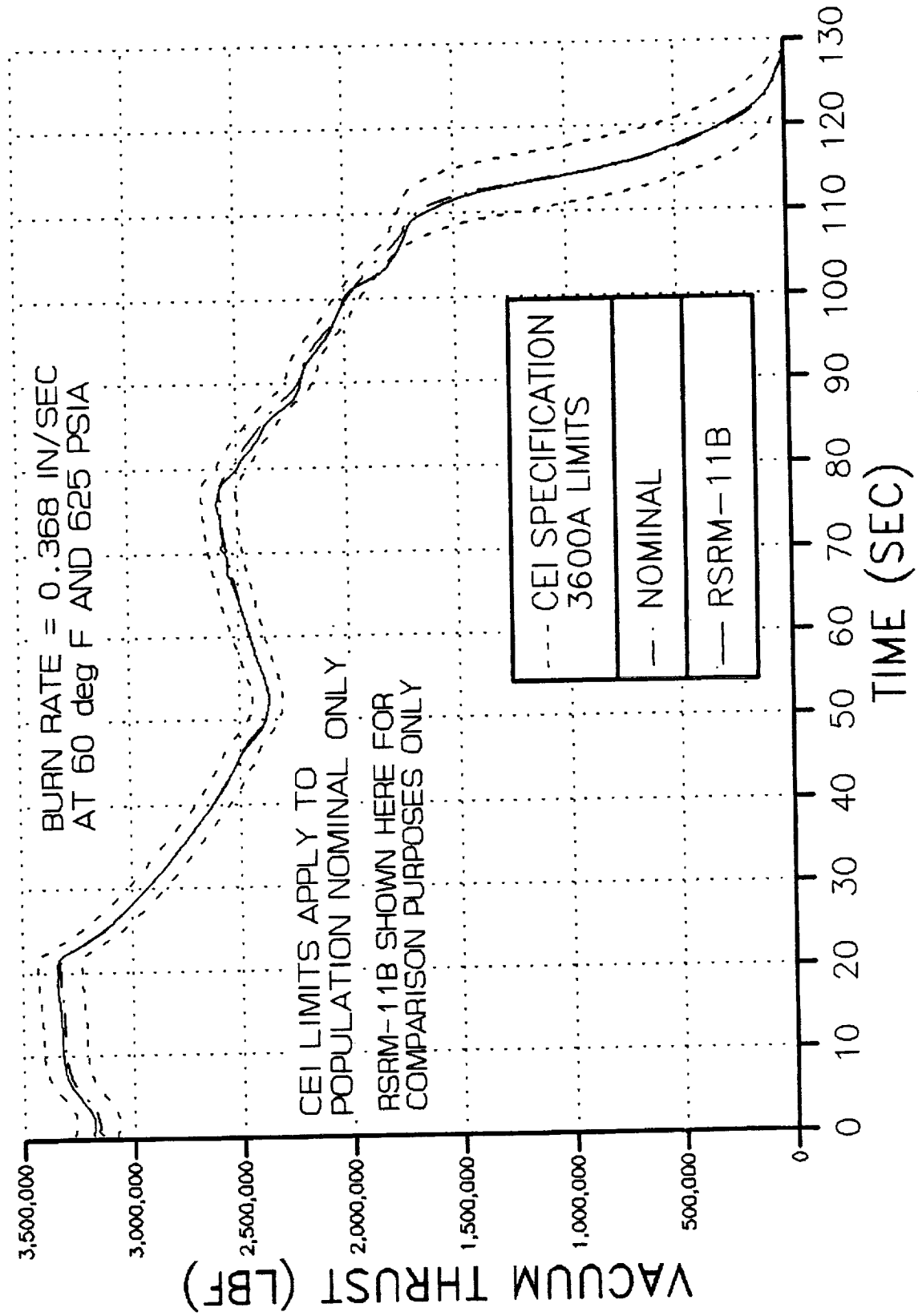

FIGURE 3.7
RSRM NOMINAL VACUUM THRUST COMPARED
TO CEI SPECIFICATION LIMITS

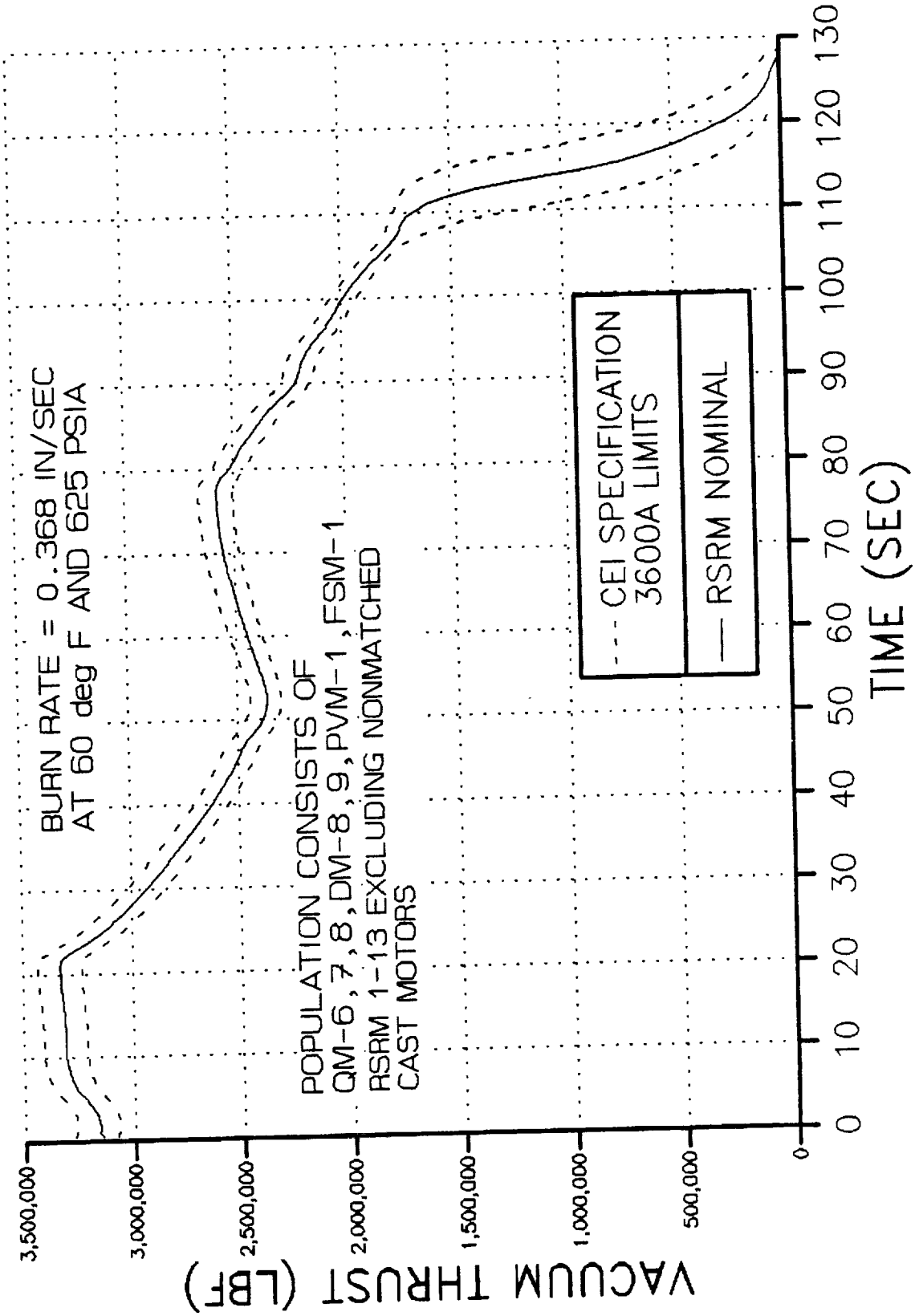

FIGURE 3.8
RSRM-11 INSTANTANEOUS THRUST IMBALANCE