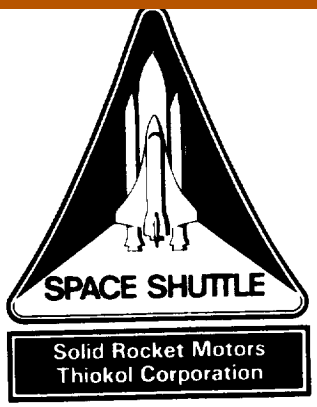

TWR-17548-10

RSRM-9 (360L009) FINAL REPORT BALLISTICS MASS PROPERTIES

20 March 1990

Prepared for:

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1.0 INTRODUCTION

This report contains the propulsion performance and reconstructed mass properties data from Thiokol's RSRM-9 motors which were assigned to the STS-36 launch. The Thiokol manufacturing designations for the motors were 360L009A/360L009B, which are referred to in this report as RSRM-9A and RSRM-9B, respectively. The launch occurred on 28 February 1990 at the Eastern Test Range (ETR). The data contained herein was input to the STS-36 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-9 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 right motor was adjusted down by 0.2 percent to closer match the other right motor OFI gauges. The OFI data on the left motor needed no adjustment. In addition, the data for both motors was adjusted up by 1% from 0 to 1 seconds and the 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 close to predicted. The delivered burn rates were 0.368 in/sec at 625 psia and 60°F for the left and the right RSRM. The predicted burn rates were 0.366 in/sec for both the left and right motors. The average of the two motors was the same as the target rate of 0.368 in/sec at 625 psia and 60°F. The performance of the two motors was very close as can be seen in Figure 2.1. The Isp on the right RSRM was low and was the second lowest experienced by a HPM/RSRM. It was within the CEI-3600 Specification limits, but 0.65 percent below the nominal value. The main engines (SSME) did not have to compensate for low performance from the RSRMs. If performance was 0.65 percent below nominal, the main engines should have been signaled to increase their output. Although no instrumentation error has been identified, the low Isp on the right motor appears to be a product of instrumentation uncertainty and not a real performance decrease. The low Isp issue is still being researched.

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 has been included. The historical average was well within the variation limits developed from the HPM Block prediction population at a burn rate of 0.368 in/sec at 625 psia and 60°F. The historical population values are the average performance data from QM-4, SRM-8, SRM-9A, SRM-10, SRM-11A, SRM-12 through SRM-19, SRM-24, ETM-1A, DM-8, DM-9, QM-6, QM-7, PVM-1, RSRM-1, RSRM-2, RSRM-3, RSRM-4A, and RSRM-5 through RSRM-9.

Post flight reconstructed RSRM mass properties are within expected values for the RSRM lightweight (RSRML) 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-9 PROPELLANT MATERIALS

Both of the ninth flight motors were cast with primarily one evaluation of propellant, E69. 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. There were however, 2 verification mixes of evaluation F67 in the left motor forward segment and 2 verification mixes from the same evaluation in the right center aft segment. 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-19066 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 90:059:07:50:22:000(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.

3.3 RSRM DELIVERED PERFORMANCE

3.3.1 RSRM-9A/RSRM-9B Thrust and Pressure Comparison

The flight motor reconstructed thrust-time traces at the delivered temperature of 67°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, 3.2.

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

Figures 3.5 and 3.6 show how RSRM-9A and RSRM-9B compared with a nominal performance average for the RSRM at standard conditions of 0.368 burn rate and 60 °F PMBT. From the figures, it is evident that the RSRM design will continue to influence the shape of the average thrust time trace near 50 seconds.

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

The reconstructed RSRM-9 propulsion performance at delivered conditions is compared to the predicted performance in Table 3.2. The actual values were slightly different than the predicted data for both motors. This difference was caused by the low Isp on both motors. The right motor's Isp was the second lowest experienced by any HPM/RSRM. The impulse values at 20 and 60 seconds, and the total impulse also reflected the low performance.

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 1.0222 and 1.0231 respectively.

The propellant mean bulk temperature (PMBT) used in the Ballistics reconstruction for both motors was 67°F. This was based on predicted 2-D temperature gradients expected in the RSRMs. Table 3.3 shows the predicted gradient (data provided by 2-D SINDA Model Aero-Thermal 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-9A and RSRM-9B 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. All values are within CEI specification requirements.

3.4.2 RSRM Nominal Thrust-Time Performance

The nominal RSRM-HPM performance is defined as the average performance of the HPM and 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-HPM population nominal thrust-time trace. This nominal RSRM-HPM 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 QM-4, SRM-8, SRM-9A, SRM-10, SRM-11A, SRM-12 through SRM-19, SRM-24, ETM-1A, DM-8, DM-9, QM-6, QM-7, PVM-1, RSRM-1, RSRM-2, RSRM-3, RSRM-4A, and RSRM-5 through RSRM-9. The delivered RSRM-HPM 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 through Figure 3.10 shows the thrust differential during steady state and tail off. All the 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-36 were well within the matched pair specification requirements.

3.5 RECONSTRUCTED MASS PROPERTIES

The Thiokol manufacturing designation, 360L009, along with RSRM-9 have been used, by Mass Properties, to identify the RSRMs used on this flight. Tables 3.9 and 3.10 provide RSRM-9A and RSRM-9B reconstructed sequential mass properties, respectively.

Table 3.11 and 3.12 compares RSRML predicted sequential weight and center of gravity (cg) data against post flight reconstructed data. A 2,000 lbm slag weight was used for both pre-fire and post-fire sequential predictions. Actual 360L009 mass properties may be obtained from Mass Properties History Log Space Shuttle 360L009-LH (TWR-17350A), dated 12 October 1989, and 360L009-RH (TWR-17351), dated 12 October 1989. Some of the mass properties data used has been taken from average actual data presented in the 5 September 1989 Mass Properties Quarterly Status Report (TWR-10211-92). 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
E69	HB Polymer	7227-0073	ASRC
	ECA	7225-0081	Dow Chemical
	Aluminum	7228-0070	Alcoa
	Iron Oxide	7226-0016	Charles Pfizer
	AP unground	7229-0080	Kerr McGee
	AP ground	7229-0080	Kerr McGee
	HB/ECA Ratio	86.7% HB	
	Iron Oxide	0.253%	
F67V	HB Polymer	7227-0075	ASRC
	ECA	7225-0083	Dow Chemical
	Aluminum	7228-0072	Alcoa
	Iron Oxide	7226-0026	Charles Pfizer
	AP unground	7229-0087	Kerr McGee
	AP ground	7229-0087	Kerr McGee
	HB/ECA Ratio	86.7% HB	
	Iron Oxide	0.249%	

TABLE 3.2 RSRM-9 PROPULSION PERFORMANCE ASSESSMENT

	(LEFT MOTOR 67 DEG) PREDICTED	ACTUAL	(RIGHT MOTOR 67 DEG) PREDICTED	ACTUAL
IMPULSE GATES				
I-20 (10^6 lbf sec)	64.81	65.03	64.76	64.91
I-60 (10^6 lbf sec)	173.07	173.50	172.97	173.16
I-AT (10^6 lbf sec)	296.97	295.76	296.87	294.93
VACUUM ISP (lbf*sec/lbm)	268.5	267.4	268.5	266.7
BURN RATE (in/sec)	0.368	0.3697	0.368	0.3700
EVENT TIMES (sec) *				
IGNITION INTERVAL	0.232	N/A	0.232	N/A
WEB TIME *	111.3	110.6	111.3	110.4
TIME OF 50 PSIA CUE	120.9	120.3	120.9	120.6
ACTION TIME *	123.0	122.2	123.0	122.4
SEPARATION COMMAND (sec)	125.8	125.5	125.8	125.5
PMBT (deg F)	67.0	67.0	67.0	67.0
MAXIMUM IGNITION RISE RATE (psia/10 ms)	91.9	N/A	91.9	N/A
DECAY TIME (sec) (59.4 psia to 85 K)	2.8	2.4	2.8	2.5
TAILOFF IMBALANCE IMPULSE DIFFERENTIAL (KLBF-SEC)	PREDICTED N/A		ACTUAL - 119	

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 IN RSRM-9

DISTANCE FROM OUTSTIDE SURFACE OF CASE (IN.)	15	45	75	105	135	165	195	225	255	285	315	345
0.0 CASE SURFACE	67.57	67.62	68.06	68.78	69.39	69.64	69.44	68.86	68.42	68.20	67.91	67.67
0.25 STEEL CASE	67.47	67.52	67.96	68.68	69.26	69.49	69.29	68.72	68.30	68.11	67.81	67.57
1.094 PROPELLANT	66.02	66.04	66.21	66.40	66.57	66.68	66.67	66.56	66.50	66.42	66.23	66.08
6.114 PROPELLANT	65.49	65.49	65.50	65.50	65.53	65.55	65.57	65.58	65.58	65.57	65.53	65.50
13.130 PROPELLANT	65.45	65.45	65.45	65.45	65.45	65.45	65.45	65.45	65.46	65.45	65.45	65.45
21.550 PROPELLANT	65.45	65.45	65.45	65.45	65.45	65.45	65.45	65.45	65.45	65.45	65.45	65.45
29.970 PROPELLANT	65.45	65.44	65.44	65.45	65.45	65.45	65.44	65.45	65.45	65.45	65.44	65.44
38.390 PROPELLANT	65.45	65.45	65.45	65.45	65.45	65.45	65.45	65.45	65.45	65.45	65.45	65.45

TABLE 3.4

COMPARISON OF RSRM-9A VARIATIONS AT PMBT = 60°F ABOUT THE NOMINAL TO THE CEI SPECIFICATION REQUIREMENTS

PARAMETER	CEI MAX 3 SIGMA VARIATION% (1)	NOMINAL VALUE (2)	RSRM-9A VALUE (3)	RSRM-9A VARIATION % (4)
WEB TIME	±5.0	111.7	111.4	-0.27
ACTION TIME	±6.5	123.4	123.0	-0.32
WEB TIME AVG PRESSURE	±5.3	660.8	660.1	+0.11
MAX PRESSURE	±6.5	918.4	912.4	-0.65
MAX SEA LEVEL THRUST	±6.2	3.06	3.07	+0.33
WEB TIME AVG VAC THRUST	±5.3	2.59	2.59	+0.00
VAC DEL SPECIFIC IMPULSE	±0.7	267.1	267.3	+0.07
WEB TIME VAC TOTAL IMPULSE	±1.0	288.9	288.0	-0.31
ACTION TIME TOTAL IMPULSE	±1.0	296.3	295.5	-0.27

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-9A AT PMBT = 60°F

(4) VARIATION = ((RSRM-9A - NOMINAL)/NOMINAL)*100

TABLE 3.5

COMPARISON OF RSRM-9B VARIATIONS AT PMBT = 60°F ABOUT THE NOMINAL TO THE CEI SPECIFICATION REQUIREMENTS

PARAMETER	CEI MAX 3 SIGMA VARIATION% (1)	NOMINAL VALUE (2)	RSRM-9B VALUE (3)	RSRM-9B VARIATION % (4)
WEB TIME	±5.0	111.7	111.2	-0.45
ACTION TIME	±6.5	123.4	123.3	-0.08
WEB TIME AVG PRESSURE	±5.3	660.8	658.5	-0.35
MAX PRESSURE	±6.5	918.4	910.6	-0.85
MAX SEA LEVEL THRUST	±6.2	3.06	3.06	+0.00
WEB TIME AVG VAC THRUST	±5.3	2.59	2.58	-0.39
VAC DEL SPECIFIC IMPULSE	±0.7	267.1	266.7	-0.15
WEB TIME VAC TOTAL IMPULSE	±1.0	288.9	286.8	-0.73
ACTION TIME TOTAL IMPULSE	±1.0	296.3	294.7	-0.54

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-9B AT PMBT = 60 F

(4) VARIATION = ((RSRM-9B - 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)	64.7
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)	296.9

(1) CEI PARAGRAPH 3.2.1.1.2.4

(2) NORMALIZED TC STANDARD CONDITIONS-BURN RATE OF 0.368 IN/SEC. POPULATION IS SAME AS USED TO COMPARE NOMINAL THRUST TRACE, Figure 3.17.

(3) IMPULSE VALUES ARE CALCULATED FROM IGNITION.

TABLE 3.7 RSRM-9 THRUST IMBALANCE SUMMARY

EVENT	IMBALANCE SPECIFICATION (KLBF)	MAXIMUM IMBALANCE (KLBF)	TIME OF MAXIMUM IMBALANCE (SEC)
STEADY STATE (1.0 SEC TO FIRST WEB TIME MINUS 4.5 SEC, LBF, 4 SEC AVERAGE)	85	+ 30.6	71.0
TRANSITION (FIRST WEB TIME MINUS 4.5 SEC TO FIRST WEB TIME, LBF)	85 - 268 LINEAR	-34.9	110.0
TAILOFF (FIRST WEB TIME TO LAST ACTION TIME)	710	- 69.9	117.0

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	+0.18
ACTION TIME	±3.0	-0.16
WEB TIME AVG PRESSURE	±2.0	+0.23
MAX PRESSURE	N/A	+0.20
MAX SEA LEVEL THRUST	N/A	+0.32
WEB TIME AVG VAC THRUST	±2.0	+0.00
VAC DEL SPECIFIC IMPULSE	±1.0	+0.24
WEB TIME VAC TOTAL IMPULSE	±1.4	+0.43
ACTION TIME TOTAL IMPULSE	±1.4	+0.26

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-9A - RSRM-9B)/RSRM-9 AVERAGE)*100
DATA AT PMBT OF 67 °F

TABLE 3.9

RSRM9-LH SEQUENTIAL MASS PROPERTIES

EVENTS/TIMES	WEIGHT (LBS)	CENTER OF GRAVITY LONG.	LAT.	VERT.	MOMENT OF INERTIA PITCH	ROLL	YAW
PRE-LAUNCH TIME = 0.00	1255293.3	1171.170	0.059	0.006	42408.326	878.960	42409.203
LIFT-OFF TIME = 0.23	1254599.0	1171.302	0.059	0.006	42365.194	877.640	42366.071
INTERMEDIATE BURN TIME = 20.00	1012815.9	1208.237	0.074	0.008	30670.635	760.451	30671.510
INTERMEDIATE BURN TIME = 40.00	791360.4	1231.692	0.094	0.010	21637.244	625.427	21638.112
MAX "Q" TIME = 54.00	661255.7	1229.292	0.111	0.012	17955.463	548.079	17956.325
INTERMEDIATE BURN TIME = 60.00	606519.4	1226.779	0.121	0.013	16550.710	511.659	16551.569
INTERMEDIATE BURN TIME = 80.00	414610.0	1215.107	0.175	0.018	11877.550	377.749	11878.398
MAX "G" TIME = 87.00	350563.3	1214.336	0.207	0.022	10493.624	327.175	10494.467
INTERMEDIATE BURN TIME = 100.00	245229.8	1227.594	0.293	0.031	8495.594	238.473	8496.430
WEB BURN TIME = 110.88	172259.6	1268.838	0.415	0.044	7239.456	171.573	7240.284
END OF ACTION TIME TIME = 122.39	144006.3	1316.195	0.495	0.053	6555.460	146.290	6556.283
SEPARATION TIME = 125.47	143361.1	1317.931	0.498	0.053	6524.752	145.813	6525.578
MAX REENTRY "Q" TIME = 320.47	142963.6	1317.893	0.499	0.052	6504.948	145.461	6505.775
NOSE CAP DEPLOYMENT TIME = 350.47	142911.5	1317.874	0.499	0.052	6502.188	145.415	6503.015
DROGUE CHUTE DEPLOYMENT TIME = 351.07	142910.4	1317.874	0.499	0.052	6502.132	145.414	6502.959
FRUSTUM RELEASE TIME = 372.17	142873.7	1317.861	0.499	0.052	6500.179	145.382	6501.005
MAIN CHUTE LINE STRETCH TIME = 373.47	142871.5	1317.860	0.499	0.052	6500.057	145.380	6500.884
MAIN CHUTE 1ST DISREEFING TIME = 383.57	142853.9	1317.855	0.499	0.052	6499.118	145.364	6499.945
MAIN CHUTE 2ND DISREEFING TIME = 389.47	142843.7	1317.851	0.499	0.052	6498.568	145.355	6499.395
NOZZLE JETTISONED TIME = 390.17	140614.2	1307.649	0.497	0.052	6299.344	140.766	6300.149
SPLASHDOWN TIME = 415.47	140570.2	1307.631	0.497	0.052	6296.968	140.727	6297.775

TABLE 3.10

RSRM9-RH SEQUENTIAL MASS PROPERTIES

EVENTS/TIMES	WEIGHT (LBS)	CENTER OF GRAVITY LONG.	LAT.	VERT.	MOMENT OFINERTIA PITCH	ROLL	YAW
PRE-LAUNCH TIME = 0.00	1254958.4	1171.147	0.059	0.006	42363.881	878.780	42364.759
LIFT-OFF TIME = 0.23	1254417.8	1171.259	0.059	0.006	42326.105	877.521	42326.983
INTERMEDIATE BURN TIME = 20.00	1012289.0	1208.168	0.073	0.008	30637.168	760.079	30638.044
INTERMEDIATE BURN TIME = 40.00	790679.0	1231.475	0.094	0.010	21615.616	624.982	21616.485
MAX "Q" TIME = 54.00	660558.9	1228.982	0.111	0.012	17939.563	547.658	17940.426
INTERMEDIATE BURN TIME = 60.00	605846.3	1226.425	0.121	0.013	16533.928	511.056	16534.787
INTERMEDIATE BURN TIME = 80.00	414498.4	1214.661	0.175	0.018	11876.598	377.682	11877.446
MAX "G" TIME = 87.00	350483.4	1213.828	0.206	0.022	10493.770	327.133	10494.613
INTERMEDIATE BURN TIME = 100.00	245480.9	1226.820	0.292	0.031	8502.831	238.721	8503.666
WEB BURN TIME = 110.66	174101.4	1266.078	0.410	0.044	7279.634	173.318	7280.462
END OF ACTION TIME TIME = 122.59	143946.4	1315.228	0.494	0.053	6561.538	146.284	6562.362
SEPARATION TIME = 125.47	143380.9	1316.652	0.497	0.053	6537.219	145.853	6538.046
MAX REENTRY "Q" TIME = 320.47	143021.0	1316.589	0.497	0.052	6516.177	145.533	6517.004
NOSE CAP DEPLOYMENT TIME = 350.47	142968.9	1316.569	0.498	0.052	6513.415	145.487	6514.242
DROGUE CHUTE DEPLOYMENT TIME = 351.07	142967.8	1316.569	0.498	0.052	6513.359	145.486	6514.186
FRUSTUM RELEASE TIME = 372.17	142931.2	1316.556	0.498	0.052	6511.403	145.454	6512.231
MAIN CHUTE LINE STRETCH TIME = 373.47	142928.9	1316.555	0.498	0.052	6511.283	145.452	6512.111
MAIN CHUTE 1ST DISREEFING TIME = 383.57	142911.3	1316.549	0.498	0.052	6510.344	145.436	6511.172
MAIN CHUTE 2ND DISREEFING TIME = 389.47	142901.1	1316.546	0.498	0.052	6509.794	145.427	6510.622
NOZZLE JETTISONED TIME = 390.17	140671.7	1306.326	0.497	0.052	6309.813	140.839	6310.617
SPLASHDOWN TIME = 415.47	140627.7	1306.308	0.497	0.052	6307.435	140.800	6308.241

TABLE 3.11

SEQUENTIAL MASS PROPERTIES PREDICTED/ACTUAL COMPARISONS
RSRM-9 Left Hand

Event	Weight (lb)				Longitudinal CG (in)			
	Predicted[1]	Actual	Delta	% Error	Predicted[1]	Actual	Delta	% Error
Pre-Ignition	1,255,293	1,255,293	0	0.00	1,171.170	1,171.170	0.000	0.00
Liftoff	1,254,658	1,254,599	-59	0.00	1,171.296	1,171.302	+0.006	0.00
Action Time	144,225	144,006	-219	0.15	1,315.534	1,316.195	+0.661	0.05
Separation[2]	143,491	143,361	-130	0.09	1,317.522	1,317.931	+0.409	0.03
Nose Cap Deployment	142,908	142,911	+3	0.00	1,317.881	1,317.874	-0.007	0.00
Drogue Chute Deployment	142,907	142,910	+3	0.00	1,317.881	1,317.874	-0.007	0.00
Main Chute Line Stretch	142,868	142,871	+3	0.00	1,317.868	1,317.860	-0.008	0.00
Main Chute 1st Disreefing	142,851	142,854	+3	0.00	1,317.862	1,317.855	-0.007	0.00
Main Chute 2nd Disreefing	142,841	142,844	+3	0.00	1,317.858	1,317.851	-0.007	0.00
Nozzle Jettison	140,613	140,614	+1	0.00	1,307.650	1,307.649	-0.001	0.00
Splash Down	140,570	140,570	0	0.00	1,307.631	1,307.631	0.000	0.00

Notes:
1. Based on Mass Properties History Log Space Shuttle 360L009-LH, 12 Octobber 1989 (TWR-17350A).
2. The separation longitudinal center of gravity of 1,317.293 is 66% of the vehicle length.

TABLE 3.12

SEQUENTIAL MASS PROPERTIES PREDICTED/ACTUAL COMPARISONS
RSRM-9 Right Hand

Event	Weight (lb)				Longitudinal CG (in)			
	Predicted[1]	Actual	Delta	% Error	Predicted[1]	Actual	Delta	% Error
Pre-Ignition	1,254,958	1,254,958	0	0.00	1,171.147	1,171.147	0.000	0.00
Liftoff	1,254,324	1,254,418	+94	0.01	1,171.274	1,171.259	-0.015	0.00
Action Time	144,284	143,946	-338	0.23	1,314.246	1,315.228	+0.982	0.07
Separation[2]	143,550	143,381	-169	0.12	1,316.225	1,316.652	+0.427	0.03
Nose Cap Deployment	142,968	142,969	+1	0.00	1,316.579	1,316.569	-0.010	0.00
Drogue Chute Deployment	142,967	142,968	+1	0.00	1,316.578	1,316.569	-0.009	0.00
Main Chute Line Stretch	142,928	142,929	+1	0.00	1,316.565	1,316.555	-0.010	0.00
Main Chute 1st Disreefing	142,910	142,911	+1	0.00	1,316.559	1,316.549	-0.010	0.00
Main Chute 2nd Disreefing	142,900	142,901	+1	0.00	1,316.555	1,316.546	-0.009	0.00
Nozzle Jettison	140,671	140,672	+1	0.00	1,306.327	1,306.326	-0.001	0.00
Splash Down	140,628	140,628	0	0.00	1,306.308	1,306.308	0.000	0.00

Notes:
1. Based on Mass Properties History Log Space Shuttle 360L009-RH, 12 October 1989 (TWR-17351).
2. The separation longitudinal center of gravity of 1,316.675 is 66% of the vehicle length.

TABLE 3.13

PREDICTED/ACTUAL WEIGHT (lb) COMPARISONS
RSRM-9 LEFT HAND

Item	Minimum	Maximum	Predicted[3]	Actual	Delta	% Error	Notes
Inerts							
Prefire, Controlled		151,076	149,187	149,187	0	0.00	1
Propellant	1,104,714		1,106,106	1,106,106	0	0.00	1
Usable			1,105,247	1,105,468	+221	0.02	2
To Liftoff			535	594	+59	9.93	
Liftoff to Action			1,104,712	1,104,874	+162	0.01	2
Unusable			859	638	-221	34.64	
Action to Separation			669	579	-90	15.54	
After Separation			190	59	-131	222.03	
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 12 October 1989, Mass Properties History Log Space Shuttle 360L009-LH (TWR-17350A).

TABLE 3.14

PREDICTED/ACTUAL WEIGHT (lb) COMPARISONS
RSRM-9 RIGHT HAND

Item	Minimum	Maximum	Predicted[3]	Actual	Delta	% Error	Notes
Inerts		151,076	149,246	149,246	0	0.00	1
Prefire, Controlled	1,104,714		1,105,712	1,105,712	0	0.00	1
Propellant			1,104,854	1,105,192	+338	0.03	2
Usable			535	440	-95	21.59	
To Liftoff			1,104,319	1,104,752	+433	0.04	2
Liftoff to Action			858	520	-338	65.00	
Unusable			668	499	-169	33.87	
Action to Separation			190	21	-169	804.76	
After Separation			2,000	2,000	0	0.00	2
Slag							

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 12 October 1989, Mass Properties History Log Space Shuttle 360L009-RH (TWR-17351).

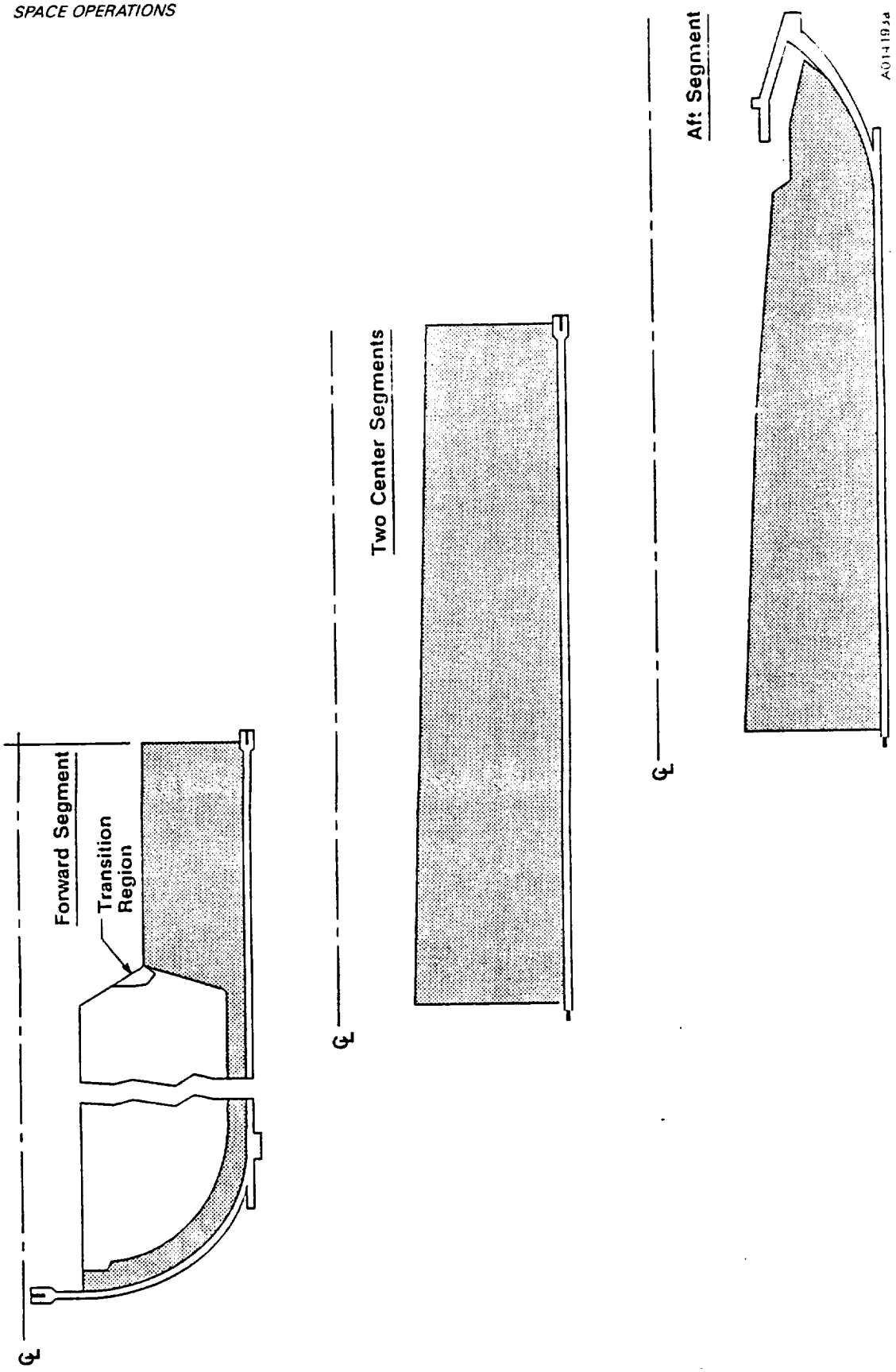

Figure 1.1 RSRM Propellant Grain Design Configuration

FIGURE 2.1
RSRM-9 Reconstructed Vacuum Thrust vs. Time
at Delivered Conditions (67 Deg. F)

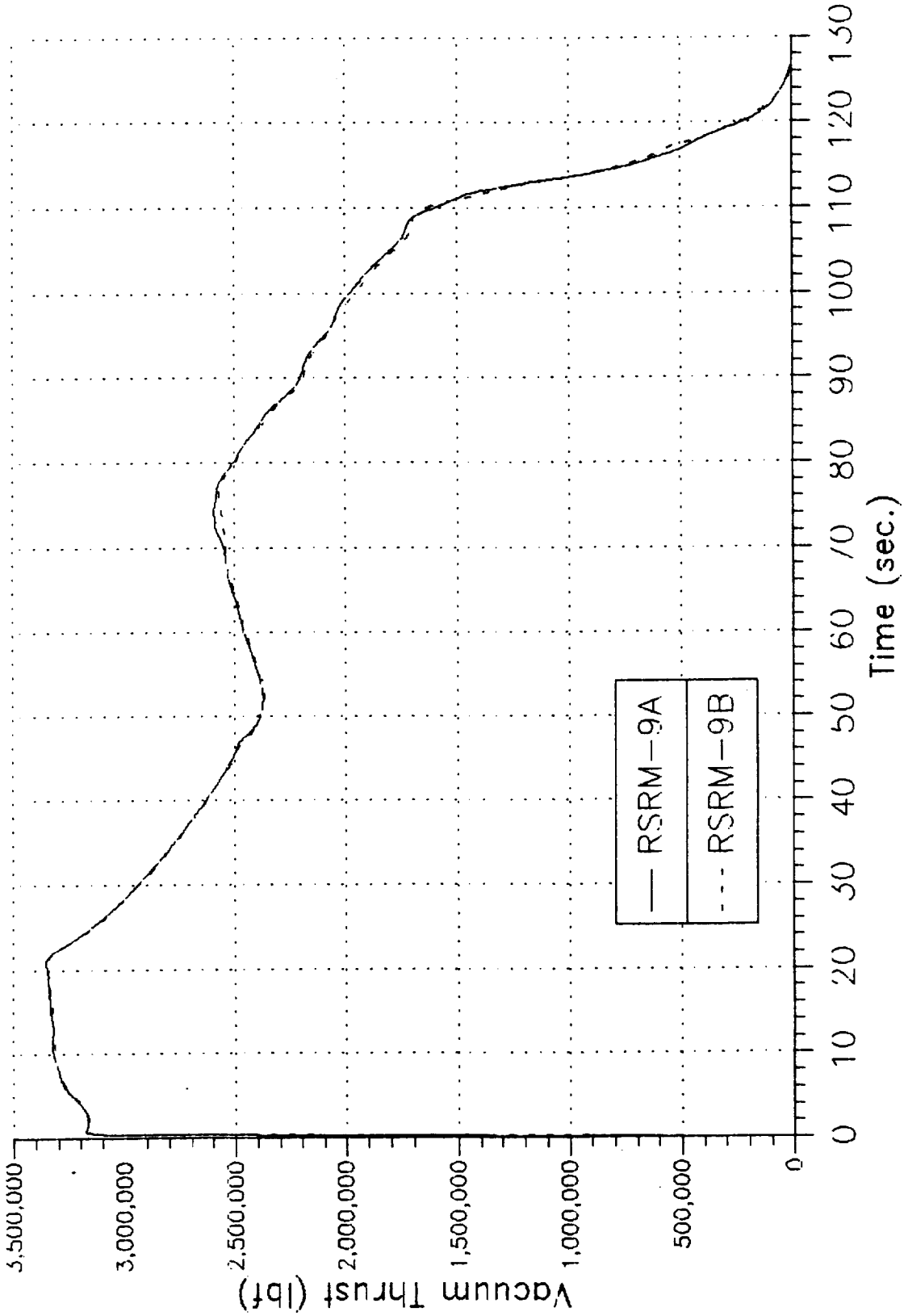

FIGURE 3.1
RSRM-9A Predicted vs. Reconstructed
Vacuum Thrust at 67 Deg. F

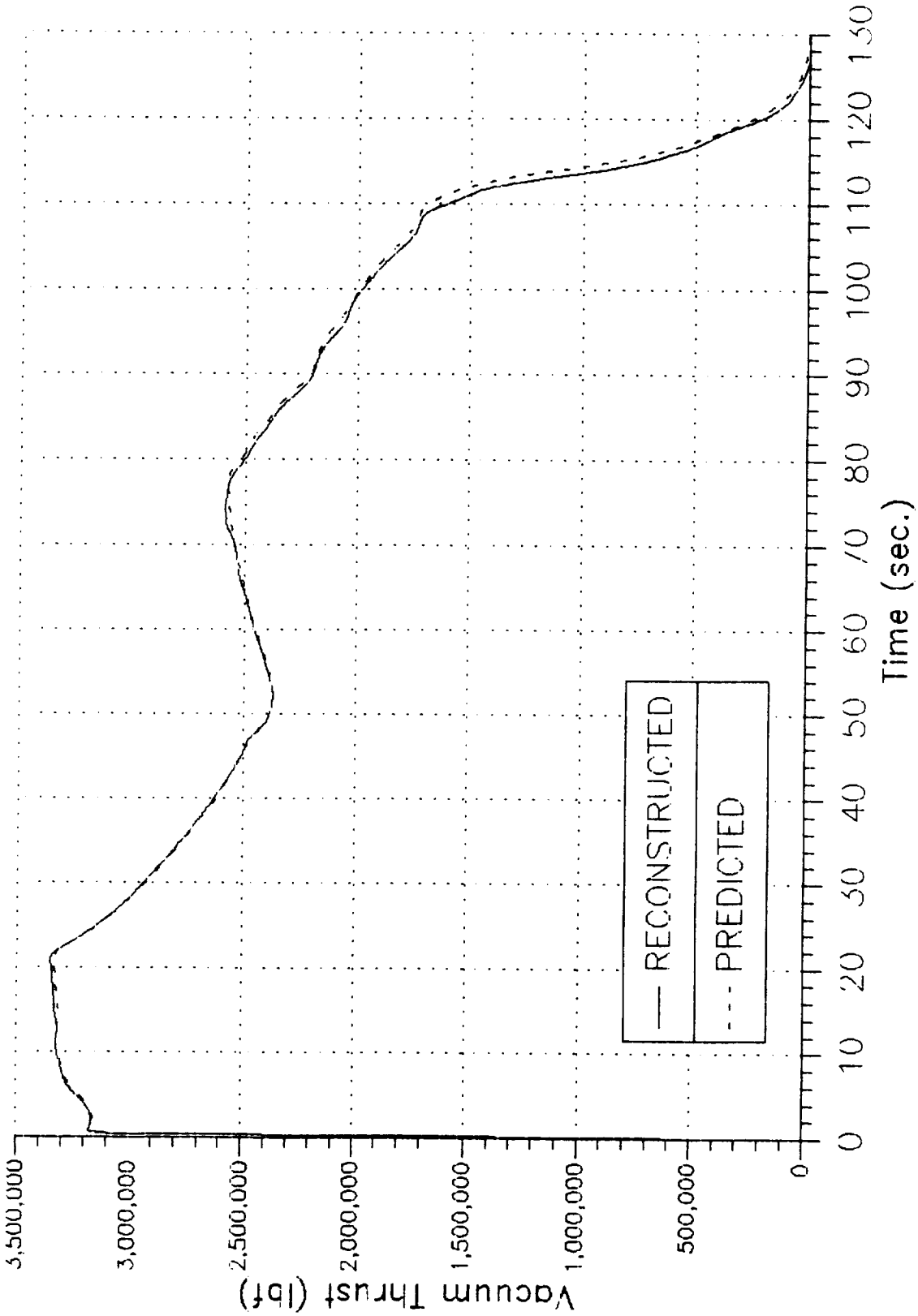

Figure 3.2
RSRM-9B Predicted vs. Reconstructed
Vacuum Thrust at 67 Deg. F

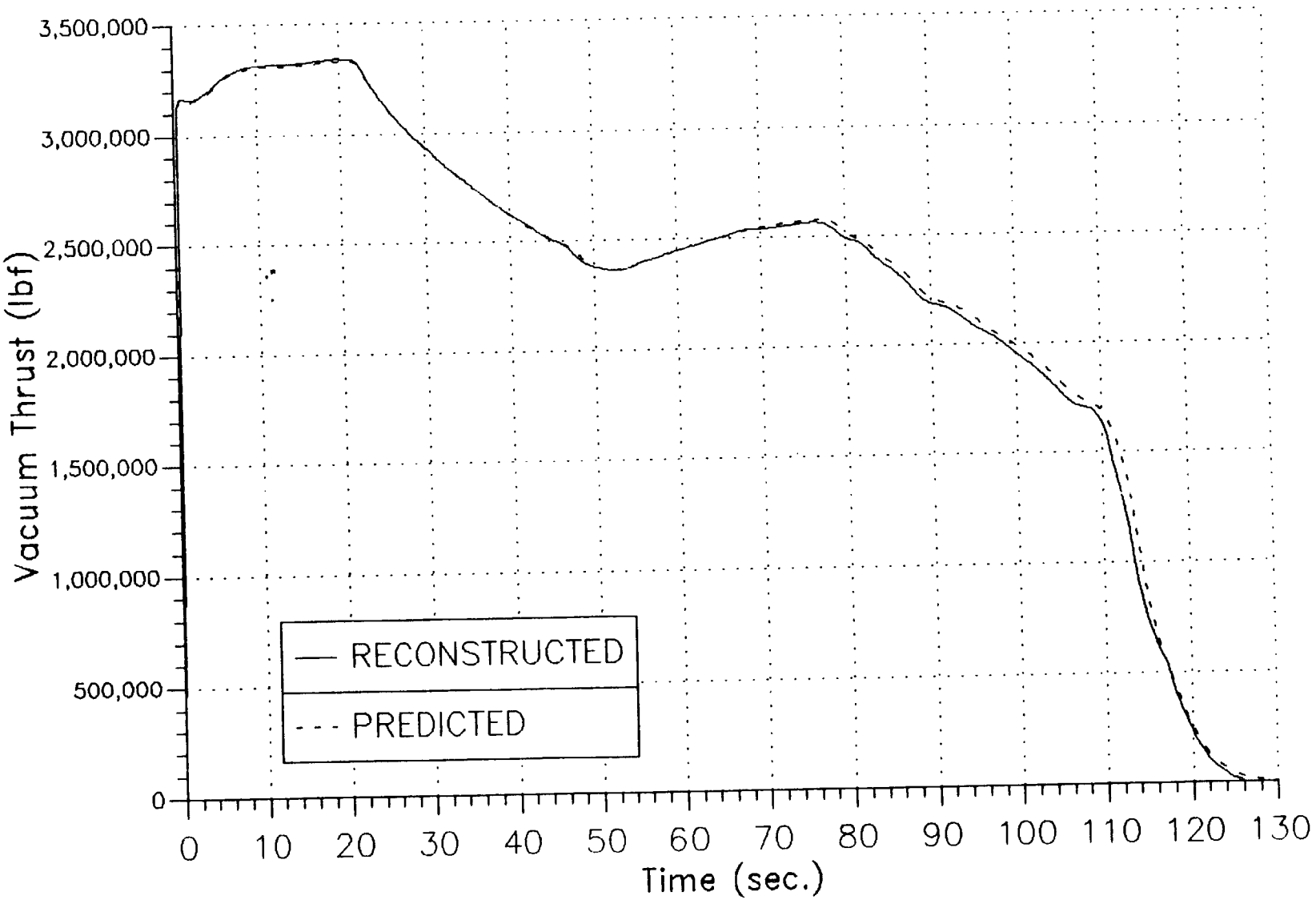

Figure 3.3
RSRM–9A Predicted vs. Measured
Chamber Pressure at 67 Deg. F

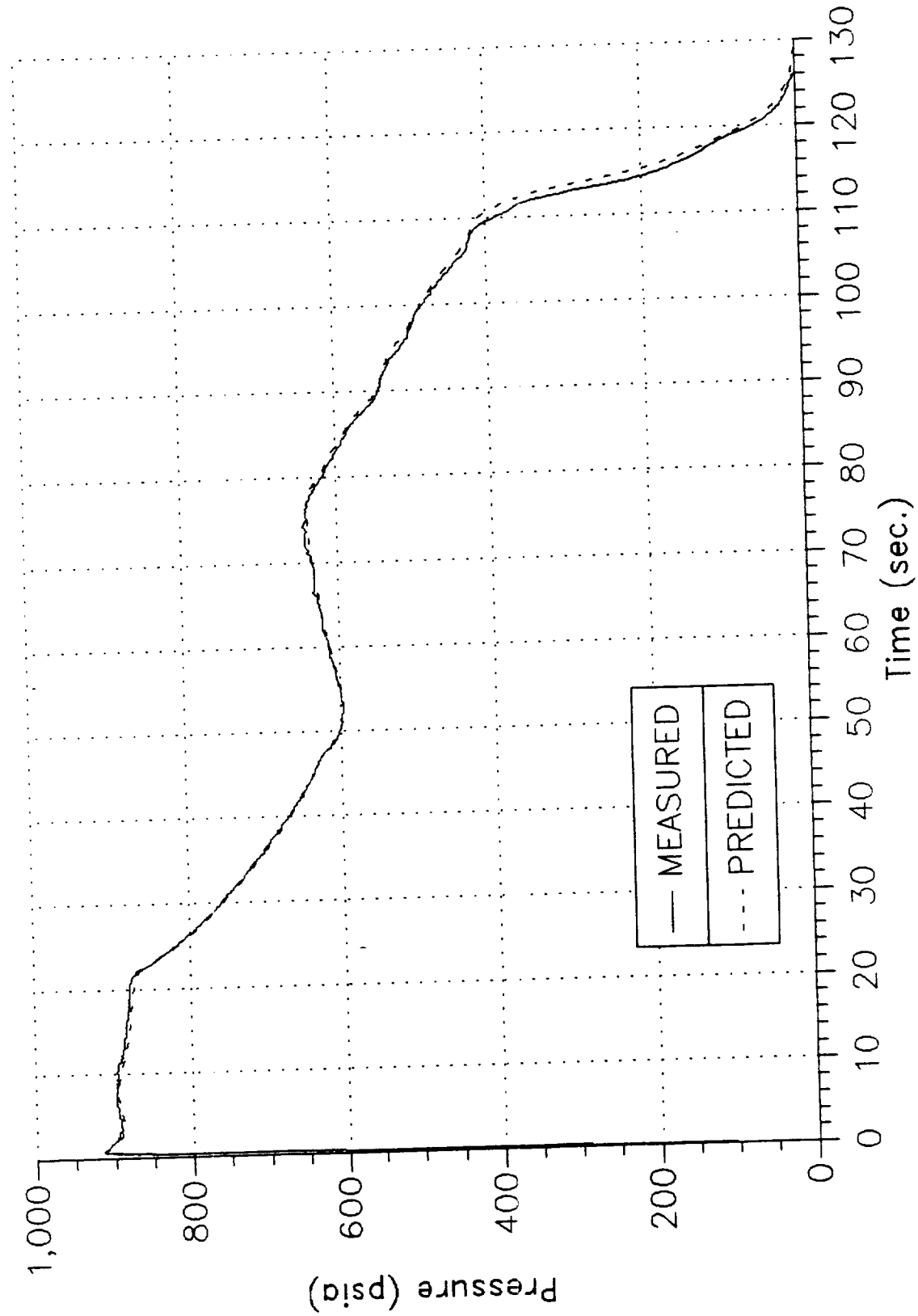

Figure 3.4
RSRM-9B Predicted vs. Measured
Chamber Pressure at 67 Deg. F

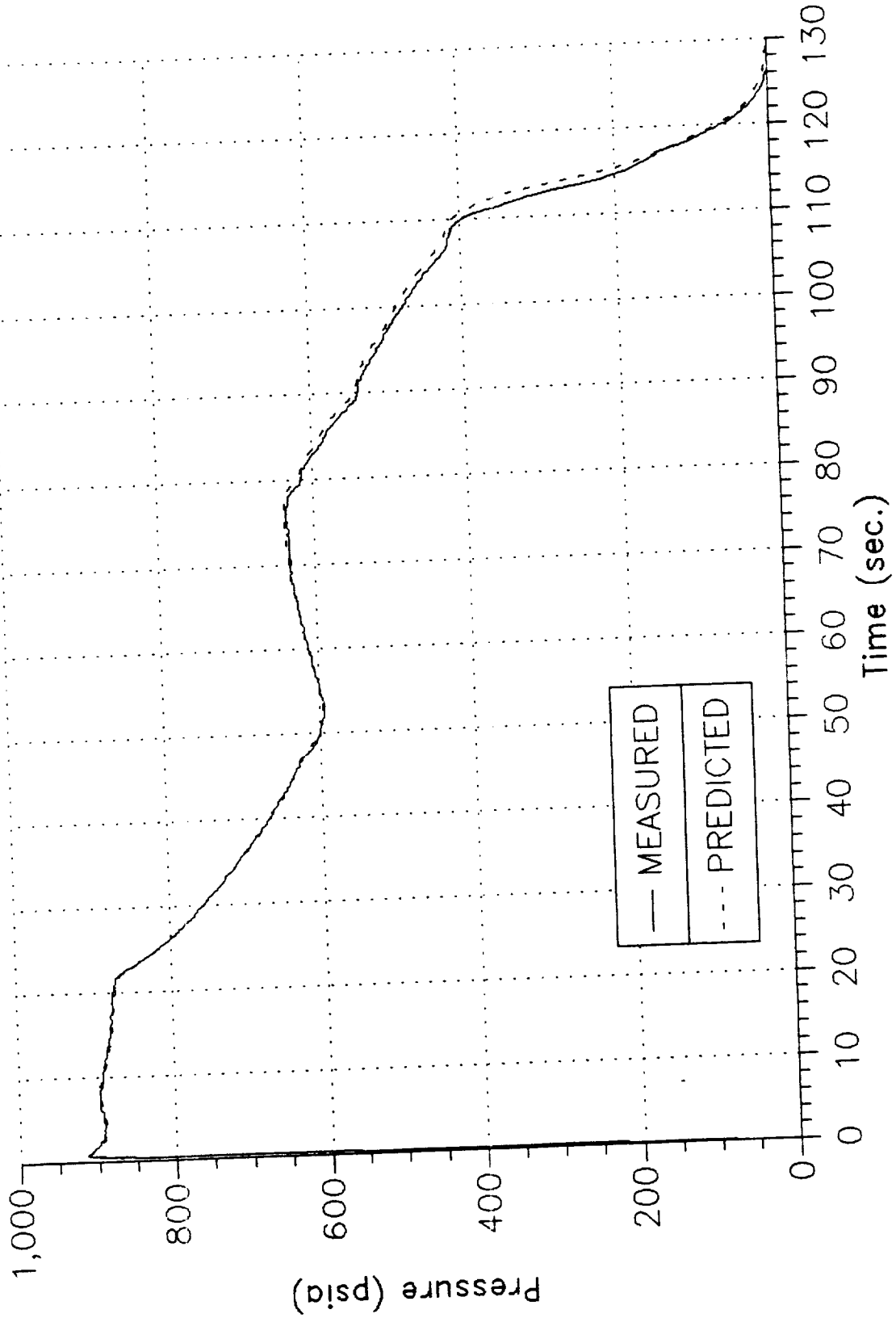

FIGURE 3.5
RSRM–9A Performance Compared to HPM/RSRM Population Nominal

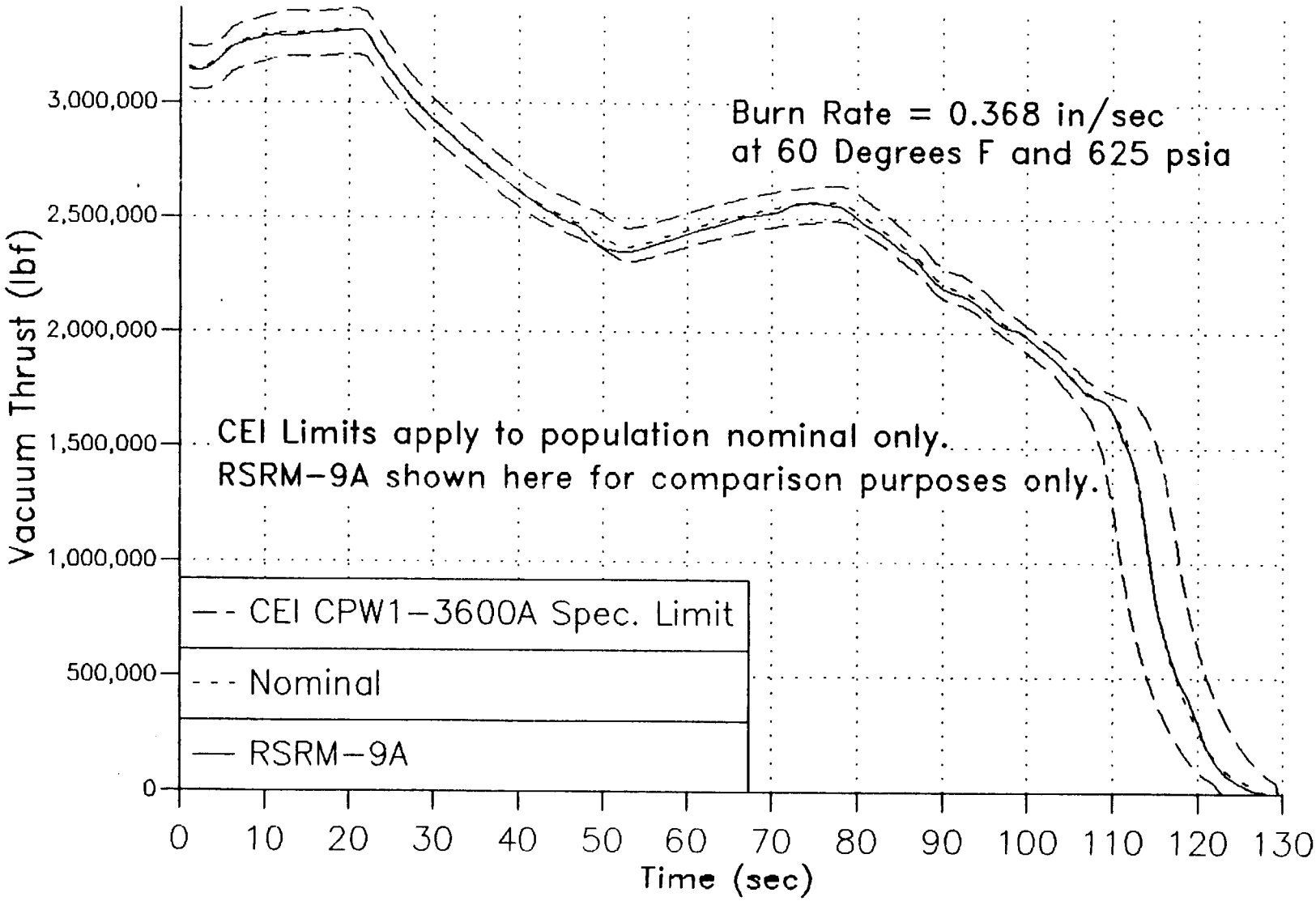

Figure 3.6
RSRM–9B Performance Compared to
HPM/RSRM Population Nominal

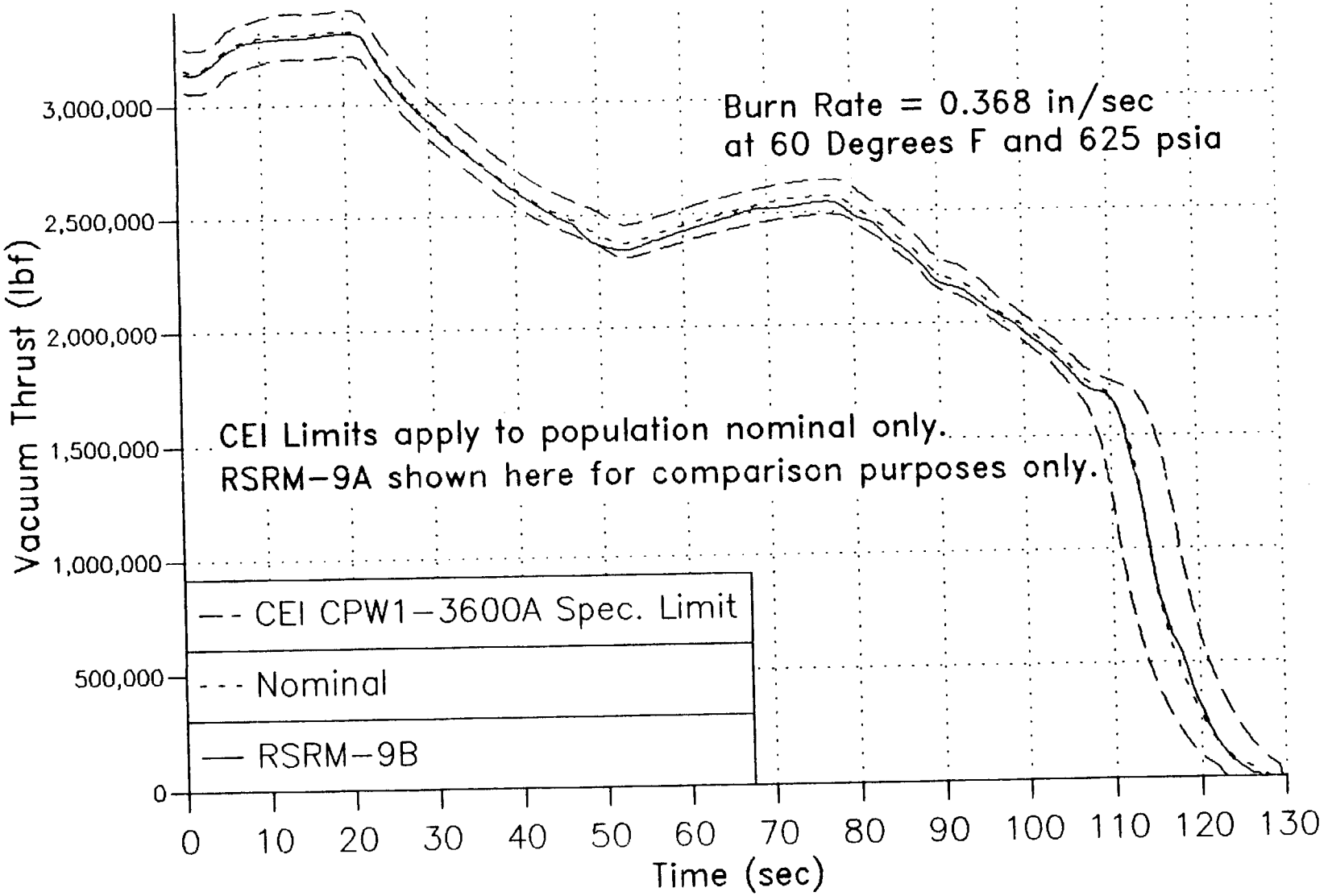

Figure 3.7
RSRM/HPM Nominal Vacuum Thrust Compared to CEI CPW1-3600A Specification Limits

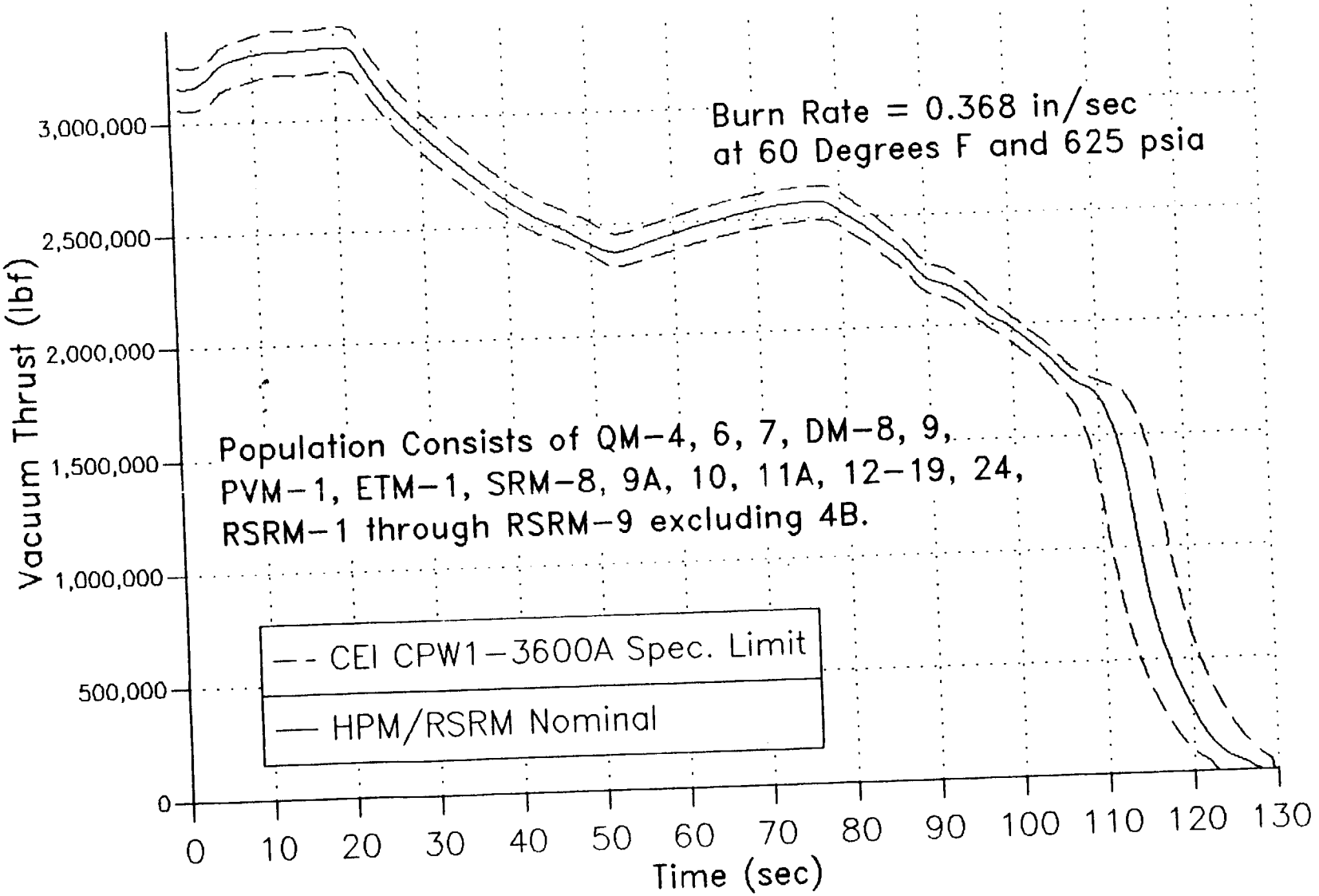

Figure 3.8
RSRM-9 Instantaneous
Steady State Thrust Imbalance

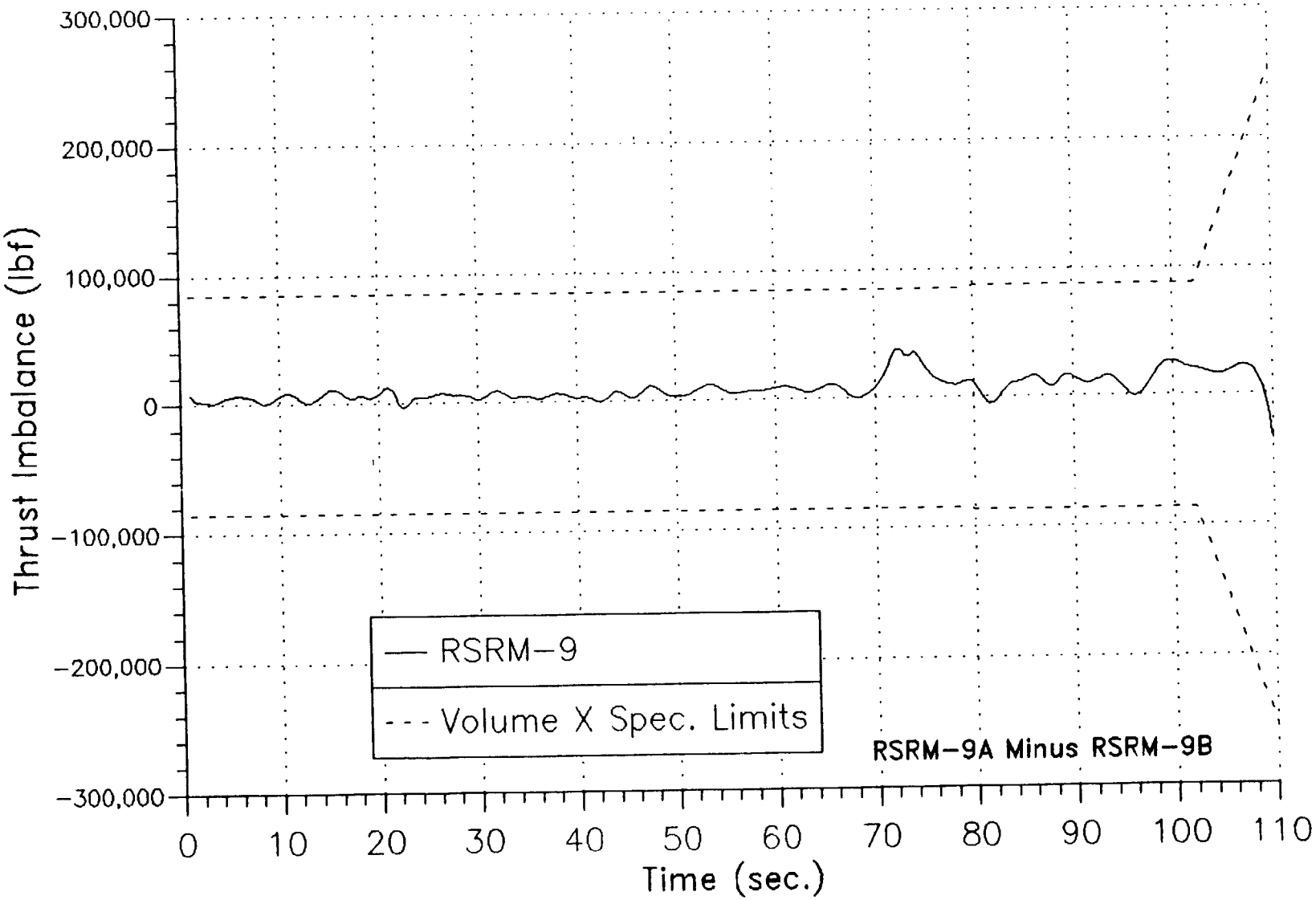

Figure 3.9
RSRM–9 4 Second Average
Steady State Thrust Imbalance

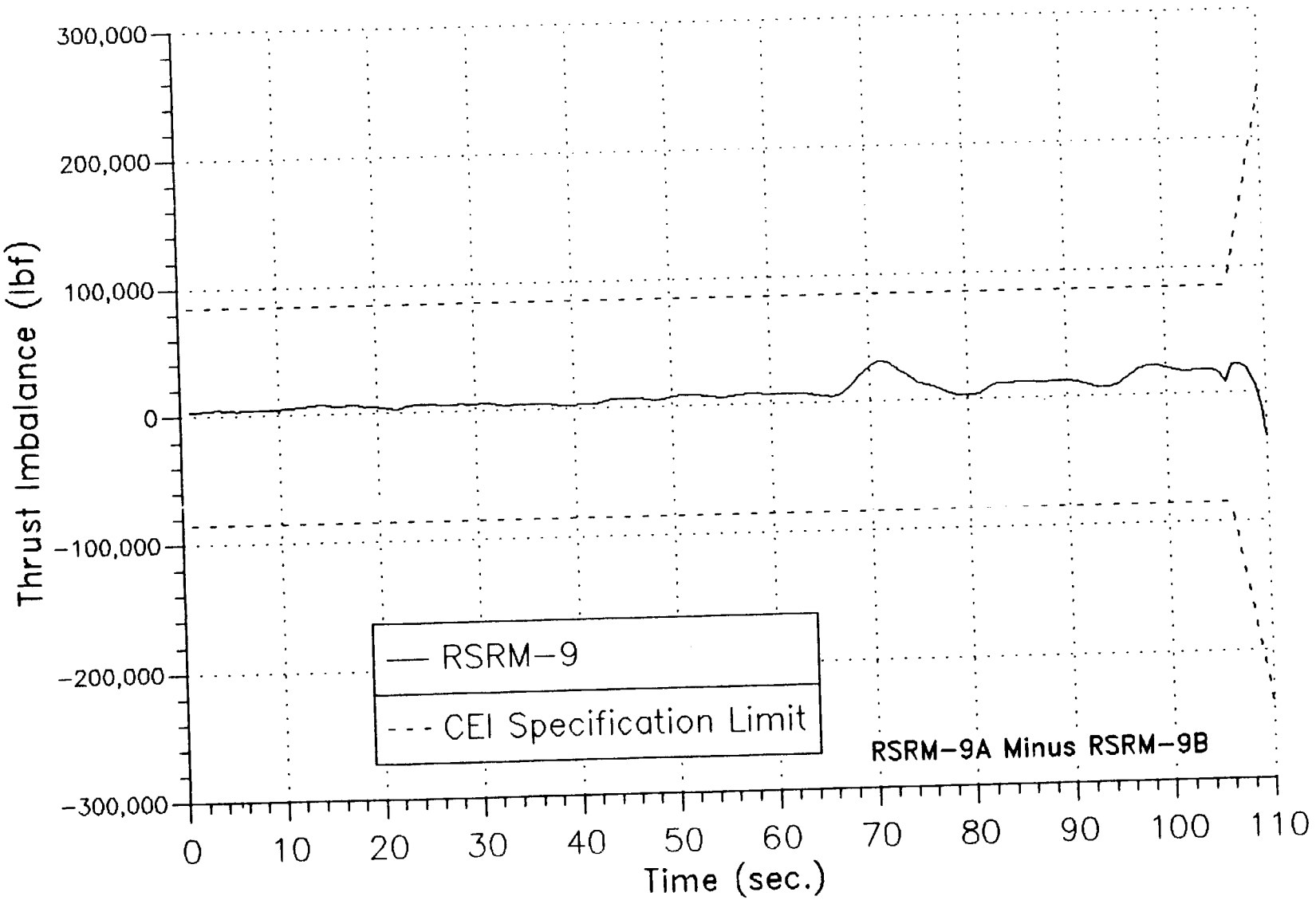

Figure 3.10
RSRM–9 Tailoff Thrust Imbalance