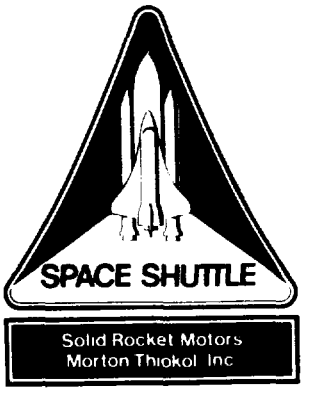

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RSRM-4 (360T004) FINAL REPORT
BALLISTICS/MASS PROPERTIES

23 JUNE 1989

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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RSRM-4 (360T004) FINAL REPORT BALLISTICS/MASS PROPERTIES

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1.0 INTRODUCTION

This report contains the propulsion performance and reconstructed mass properties data from Morton Thiokol's RSRM-4 motors which were assigned to the STS-30R launch. The Morton Thiokol manufacturing designation for the motors were 360Q004A/360H004B, which are referred to in this report as RSRM-4A and RSRM-4B, respectively. The launch occurred on 4 May 1989 at the Eastern Test Range (ETR). The data contained herein was input to the STS-30R 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-4 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 OFI data on the left motor was adjusted up by 0.4 percent to closer match the other OFI gauges. No high sample rate pressure gauges, Development Flight Instrumentaion (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 0.3684 and 0.3685 in/sec at 625 psia and 60°F for the left and right motors respectively. The predicted burn rates were 0.368 in/sec and 0.370 in/sec respectively. The average of the two motors was 0.0005 in/sec above the target rate of 0.368 in/sec at 625

psia and 60°F. The performance of the two motors were very close to the same as can be seen in Figure 2.1.

The performance of the pair of motors were compared to the following CEI Specification CPW1-3600 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 and RSRM-4A. The motors used in the HPM Block prediction population were QM-4, SRM-8A, 8B, 9A, 10A, 10B, 11B, 13A, and 13B.

Post flight reconstructed RSRM mass properties are within expected values for the RSRM quarterweight (RSRMQ) and halfweight (RSRMH) 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-4 PROPELLANT MATERIALS

Both of the fourth flight motors were cast with primarily one evaluation of propellant, E64. 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. However, the aft segment on the right motor was a segment originally cast as QM-8 and contains several evaluations. The evaluations contained in this aft segment are E62 and residual materials from evaluations E60, E61, and E63. There were also 2 mixes of verification evaluation E65 in the left

motor 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. See document TWR-19061 Rev. A for more information on propellant materials for this flight set.

3.2 RSRM PROPULSION PERFORMANCE ANALYSIS

All times shown in this section, unless noted otherwise are referenced to the RSRM ignition command time at 1989:124:18:46:59:011 (GMT).

As previously mentioned the OFI (12.5 s/s) data was used for the steady state and tail off performance assessment. It compared well with the real time data although the left motor OFI data needed to be adjusted up 0.4 percent after review of all the data.

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-4A/RSRM-4B Thrust and Pressure Comparison

The flight motor reconstructed thrust-time traces at the delivered temperature of 71°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-4A and RSRM-4B 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-4 propulsion performance is compared to the predicted performance in Table 3.2. The actual values are very close to the predicted data for both motors and well within specification limits.

A comparison of actual and predicted propellant burn rates to the target burn rate for the flight RSRMs at a PMBT of 60°F and 625 psia is shown in Figure 3.7. 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 respectively were 1.0177 and 1.0152.

The predicted propellant mean bulk temperature (PMBT) used in the Ballistics prediction for both motors was 71°F. This was based on predicted 2-D temperature gradients expected in the RSRMs. Table 3.3 shows the predicted gradient (data provided by 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-4A and RSRM-4B 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.

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, and RSRM-4A. 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 3.8.

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 3.9).

3.4.4 Matched Pair Thrust Differential

The maximum thrust imbalance assessment is shown in Table 3.7. Figure 3.9 through Figure 3.11 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.

It should be noted that because of the swap out of the aft segment on RSRM-4B, a waiver was written for this flight set to remove the thrust imbalance requirement. The possibility of thrust imbalance greater than the current limits existed due to the non-matched cast aft segments. Preliminary calculations showed a possible exceedence of 10,700 lbf at 88 seconds of the NSTS-07700 Volume X Specification. See waiver PCIN 41800, dated 01/19/89, for further information.

3.4.5 Matched Pair Performance Requirements

The CEI Specification requires that the performance of a matched pair of motors on a flight set have similar performance according to Table 3.8. The RSRMs for STS-30R were well within the matched pair specification requirements.

3.5 RECONSTRUCTED MASS PROPERTIES

The Morton Thiokol manufacturing designation, 360Q004A and 360H004B, along with STS-30 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 STS-30A and STS-30B reconstructed sequential mass properties, respectively.

Table 3.11 compares the quarterweight redesigned shuttle rocket motor (RSRMQ) predicted sequential weight and center of gravity (cg) data with the postflight reconstructed data. Table 3.12 compares the halfweight redesigned shuttle rocket motor (RSRMH) predicted sequential weight and center of gravity (cg) data with postflight reconstructed data, also. Actual STS-30 mass properties may be obtained from Mass Properties History Log Space Shuttle 360Q004-LH (TWR-17340), dated 9 January 1989, and 360H004-RH (TWR-17341), dated 9 January 1989. Some of the mass properties data used has been taken from average actual data presented in the 5 December 1988 Mass Properties Quarterly Status Report (TWR-10211-89). Postflight reconstructed data reflects Ballistics mass flow data from the 12.5 sample per second measured pressure traces and a predicted slag weight of 1518 lbs.

Tables 3.13 and 3.14 presents CEI requirements, predicted, and actual weight comparisons. Mass properties data for both RSRM configurations complies with the CEI specification requirements (CPW1-3600A, G, Part I).

TABLE 3.1
RAW MATERIAL EVALUATION SUMMARY

TP-H1148 PROPELLANT EVALUATION	INGREDIENT	STOCK-LOT	VENDOR
E60	HB Polymer	7227-0061	ASRC
	ECA	7225-0067	Dow Chemical
	Aluminum	7228-0060	Reynolds
	Fe203	7226-0015	Charles Pfizer
	AP unground	7229-0061	Kerr McGee
	AP ground	7229-0061	Kerr McGee
E61	HB Polymer	7227-0065	ASRC
	ECA	7225-0073	Dow Chemical
	Aluminum	7228-0062	ALCAN
	Fe203	7226-0021	Charles Pfizer
	AP unground	7229-0073	Kerr McGee
	AP ground	7229-0073	Kerr McGee
E62	HB Polymer	7227-0066	ASRC
	ECA	7225-0074	Dow Chemical
	Aluminum	7228-0063	ALCOA
	Fe203	7226-0021	Charles Pfizer
	AP unground	7229-0070	PEPCON
	AP ground	7229-0070	PEPCON
E63	HB Polymer	7227-0067	ASRC
	ECA	7225-0075	Dow Chemical
	Aluminum	7228-0064	ALCAN
	Fe203	7226-0021	Charles Pfizer
	AP unground	7229-0071	PEPCON
	AP ground	7229-0071	PEPCON
E64	HB Polymer	7227-0068	ASRC
	ECA	7225-0076	Dow Chemical
	Aluminum	7228-0065	ALCAN
	Fe203	7226-0021	Charles Pfizer
	AP unground	7229-0074	Kerr McGee
	AP ground	7229-0074	Kerr McGee
E65V	HB Polymer	7227-0069	ASRC
	ECA	7225-0077	Dow Chemical
	Aluminum	7228-0066	ALCAN
	Fe203	7226-0021	Charles Pfizer
	AP unground	7229-0076	Kerr McGee
	AP ground	7229-0076	Kerr McGee

TABLE 3.2 RSRM-4 PROPULSION PERFORMANCE ASSESSMENT

	(LEFT MOTOR 71 DEG) PREDICTED	ACTUAL	(RIGHT MOTOR 71 DEG) PREDICTED	ACTUAL
IMPULSE GATES				
I-20 (10^6 lbf sec)	65.73	65.42	66.15	65.42
I-60 (10^6 lbf sec)	174.63	174.71	175.21	174.73
I-AT (10^6 lbf sec)	296.88	296.20	296.82	296.10
VACUUM ISP (lbf*sec/lbm)	268.3	267.6	268.3	267.6
BURN RATE (in/sec) (at 625 psia reference pressure)	0.3710	0.3713	0.3725	0.3714
EVENT TIMES (sec) *				
IGNITION INTERVAL	0.232	N/A	0.232	N/A
WEB TIME *	109.7	109.8	109.1	110.2
TIME OF 50 PSIA CUE	118.7	119.7	118.6	120.1
ACTION TIME *	120.8	122.2	120.7	122.6
SEPARATION COMMAND (sec)	123.6	125.0	123.6	125.0
PMBT (deg F)	71.0	71.0	71.0	71.0
MAXIMUM IGNITION RISE RATE (psia/10 ms)	91.9	N/A	91.9	N/A
DECAY TIME (sec) (59.4 psia to 85 K)	2.9	3.2	2.9	3.6
TAILOFF IMBALANCE IMPULSE DIFFERENTIAL (KLBF-SEC)	PREDICTED + 284		ACTUAL - 77	

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-4

TEMPERATURE GRADIENTS								
	DEGREE LOCATIONS							
WEB DISTANCE*	0	45	90	135	180	225	270	315
0.0	82.6	76.4	75.1	75.7	75.7	76.1	80.8	85.7
2.63	82.0	71.5	69.1	69.4	69.5	70.2	81.9	90.3
7.88	75.1	68.6	66.9	67.0	67.0	67.9	74.9	79.5
14.19	74.1	69.5	66.7	66.6	66.7	67.9	73.8	77.8
21.56	73.3	68.4	66.4	66.3	66.5	67.9	73.0	76.3
28.94	72.6	68.3	66.3	66.1	66.3	67.9	72.4	75.2
36.31	72.2	68.2	66.3	65.9	66.2	67.9	72.0	74.5

* MEASURED FROM CASE WALL TOWARD CENTER OF SEGMENT (INCHES)

TABLE 3.4

COMPARISON OF RSRM-4A VARIATIONS AT PMBT = 60°F ABOUT THE NOMINAL TO THE CEI SPECIFICATION REQUIREMENTS

PARAMETER	CEI MAX 3 SIGMA VARIATION% (1)	NOMINAL VALUE (2)	RSRM-4A VALUE (3)	RSRM-4A VARIATION % (4)
WEB TIME	±5.0	111.7	111.1	-0.54
ACTION TIME	±6.5	123.4	123.5	+0.08
WEB TIME AVG PRESSURE	±5.3	660.8	662.5	+0.26
MAX PRESSURE	±6.5	918.4	909.2	-1.00
MAX SEA LEVEL THRUST	±6.2	3.06	3.08	+0.65
WEB TIME AVG VAC THRUST	±5.3	2.59	2.59	+0.00
VAC DEL SPECIFIC IMPULSE	±0.7	267.1	267.5	+0.15
WEB TIME VAC TOTAL IMPULSE	±1.0	288.9	288.4	-0.17
ACTION TIME TOTAL IMPULSE	±1.0	296.3	296.0	-0.10

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

(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-4A AT PMBT = 60°F

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

TABLE 3.5

COMPARISON OF RSRM-4B VARIATIONS AT PMBT = 60°F ABOUT THE NOMINAL TO THE CEI SPECIFICATION REQUIREMENTS

PARAMETER	CEI MAX 3 SIGMA VARIATION% (1)	NOMINAL VALUE (2)	RSRM-4A VALUE (3)	RSRM-4A VARIATION % (4)
WEB TIME	±5.0	111.7	111.5	-0.18
ACTION TIME	±6.5	123.4	124.0	+0.49
WEB TIME AVG PRESSURE	±5.3	660.8	661.2	+0.06
MAX PRESSURE	±6.5	918.4	906.7	-1.27
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	267.4	+0.11
WEB TIME VAC TOTAL IMPULSE	±1.0	288.9	288.6	-0.10
ACTION TIME TOTAL IMPULSE	±1.0	296.3	295.9	-0.13

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

(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-4B AT PMBT = 60 F

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

TABLE 3.6

RSRM-HPM POPULATION
IMPULSE GATES

IMPULSE	REQUIREMENT (1)	STANDARD NOMINAL (2)
Impulse at 20 sec (10**6 LBF-SEC)	63.1 (MIN)	64.5
Impulse at 60 sec (10**6 LBF-SEC)	171.2 - 178.1 172.9 (+3%,-1%)	172.7
Impulse at ACTION TIME (10**6 LBF-SEC)	293.8 (MIN)	296.6

(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 3.17.

TABLE 3.7 RSRM-4 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	+ 22.6	94.5
TRANSITION (FIRST WEB TIME MINUS 4.5 SEC TO FIRST WEB TIME, LBF)	85 - 268 LINEAR	+ 44.2	109.5
TAILOFF (FIRST WEB TIME TO LAST ACTION TIME)	710	+ 53.5	112.0

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	+0.36
ACTION TIME	±3.0	+0.40
WEB TIME AVG PRESSURE	±2.0	-0.20
MAX PRESSURE	N/A	-0.28
MAX SEA LEVEL THRUST	N/A	-0.33
WEB TIME AVG VAC THRUST	±2.0	+0.00
VAC DEL SPECIFIC IMPULSE	±1.0	-0.04
WEB TIME VAC TOTAL IMPULSE	±1.4	+0.07
ACTION TIME TOTAL IMPULSE	±1.4	-0.03

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

(1) CEI SPECIFICATION PARAGRAPH 3.2.1.1.2.2, TABLE II

(2) VARIATION = ((RSRM-4B - RSRM-4A)/RSRM-4 AVERAGE)*100
DATA AT PMBT OF 60 DEG F

Table 3.9

STS-30 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	1256224.2	1171.186	0.058	0.006	42481.747	873.019	42482.561
LIFT-OFF TIME = 0.23	1255482.9	1171.341	0.058	0.006	42435.700	871.366	42436.514
INTERMEDIATE BURN TIME = 20.00	1012465.3	1208.516	0.071	0.007	30689.580	753.307	30690.391
INTERMEDIATE BURN TIME = 40.00	789649.0	1231.895	0.091	0.009	21634.024	617.565	21634.829
MAX "Q" TIME = 54.00	658677.7	1229.351	0.108	0.011	17952.501	539.892	17953.299
INTERMEDIATE BURN TIME = 60.00	603531.4	1226.763	0.118	0.012	16530.869	502.329	16531.665
INTERMEDIATE BURN TIME = 80.00	410397.0	1215.277	0.172	0.018	11846.599	367.955	11847.382
MAX "G" TIME = 87.00	346521.7	1215.019	0.202	0.022	10477.867	317.422	10478.646
INTERMEDIATE BURN TIME = 100.00	241309.4	1229.650	0.289	0.031	8491.205	228.570	8491.976
WEB BURN TIME = 110.06	173669.6	1267.846	0.399	0.043	7315.657	167.022	7316.423
END OF ACTION TIME TIME = 122.42	143901.6	1314.710	0.480	0.052	6605.726	140.693	6606.486
SEPARATION TIME = 125.00	143231.5	1316.169	0.483	0.052	6582.883	140.107	6583.646
MAX REENTRY "Q" TIME = 320.00	142780.7	1316.027	0.484	0.051	6560.380	139.698	6561.144
NOSE CAP DEPLOYMENT TIME = 335.03	142751.9	1316.017	0.484	0.051	6558.840	139.672	6559.604
DROGUE CHUTE DEPLOYMENT TIME = 335.63	142750.8	1316.016	0.484	0.051	6558.779	139.671	6559.543
FRUSTUM RELEASE TIME = 356.73	142710.3	1316.002	0.484	0.051	6556.606	139.636	6557.370
MAIN CHUTE LINE STRETCH TIME = 358.03	142707.8	1316.001	0.484	0.051	6556.472	139.633	6557.236
MAIN CHUTE 1ST DISREEFING TIME = 368.13	142688.4	1315.995	0.484	0.051	6555.427	139.616	6556.191
MAIN CHUTE 2ND DISREEFING TIME = 374.03	142677.1	1315.991	0.484	0.051	6554.816	139.606	6555.580
NOZZLE JETTISONED TIME = 374.73	140465.5	1305.781	0.482	0.051	6354.589	134.182	6355.334
SPLASHDOWN TIME = 386.45	140443.0	1305.772	0.482	0.051	6353.368	134.162	6354.113

Table 3.10

STS-30 RH SEQUENTIAL MASS PROPERTIES

EVENTS/TIMES	WEIGHT (LBS)	CENTER OF GRAVITY LONG.	LAT.	VERT.	MOMENT OF INERTIA PITCH	ROLL	YAW
PRE-LAUNCH TIME = 0.00	1256695.3	1171.305	0.058	0.006	42471.998	879.786	42472.841
LIFT-OFF TIME = 0.23	1256040.9	1171.434	0.058	0.006	42431.498	878.479	42432.341
INTERMEDIATE BURN TIME = 20.00	1012939.9	1208.545	0.071	0.008	30679.197	760.601	30680.037
INTERMEDIATE BURN TIME = 40.00	790245.3	1231.813	0.091	0.010	21625.742	624.857	21626.576
MAX "Q" TIME = 54.00	659232.7	1229.261	0.108	0.012	17937.746	546.858	17938.574
INTERMEDIATE BURN TIME = 60.00	603875.6	1226.642	0.118	0.013	16508.842	508.919	16509.666
INTERMEDIATE BURN TIME = 80.00	410859.0	1215.156	0.171	0.019	11831.607	374.559	11832.420
MAX "G" TIME = 87.00	347176.1	1214.928	0.202	0.022	10469.086	324.097	10469.894
INTERMEDIATE BURN TIME = 100.00	242561.5	1229.335	0.287	0.032	8496.556	235.596	8497.357
WEB BURN TIME = 110.40	172854.3	1269.030	0.401	0.045	7283.814	172.013	7284.607
END OF ACTION TIME TIME = 122.86	144610.1	1315.556	0.478	0.054	6581.540	147.433	6582.329
SEPARATION TIME = 125.00	143996.9	1317.410	0.480	0.054	6550.490	147.070	6551.282
MAX REENTRY "Q" TIME = 320.00	143503.0	1317.601	0.481	0.053	6521.886	146.660	6522.679
NOSE CAP DEPLOYMENT TIME = 350.00	143449.3	1317.582	0.481	0.053	6519.035	146.612	6519.827
DROGUE CHUTE DEPLOYMENT TIME = 350.60	143448.2	1317.582	0.481	0.053	6518.977	146.611	6519.770
FRUSTUM RELEASE TIME = 371.70	143410.5	1317.570	0.482	0.053	6516.958	146.578	6517.751
MAIN CHUTE LINE STRETCH TIME = 373.00	143408.1	1317.569	0.482	0.053	6516.834	146.576	6517.627
MAIN CHUTE 1ST DISREEFING TIME = 383.10	143390.1	1317.563	0.482	0.053	6515.864	146.560	6516.657
MAIN CHUTE 2ND DISREEFING TIME = 389.00	143379.5	1317.560	0.482	0.053	6515.296	146.550	6516.089
NOZZLE JETTISONED TIME = 389.70	141179.6	1307.380	0.480	0.052	6316.978	141.255	6317.752
SPLASHDOWN TIME = 406.89	141148.9	1307.368	0.480	0.052	6315.314	141.228	6316.087

Table 3.11

SEQUENTIAL MASS PROPERTIES PREDICTED/ACTUAL COMPARISONS
STS-30 Left Hand

Event	Weight (lb)				Longitudinal CG (in)			
	Predicted[1]	Actual	Delta	% Error	Predicted[1]	Actual	Delta	% Error
Pre-Ignition	1,256,224	1,256,224	0	0.00	1,171.186	1,171.168	0.000	0.00
Liftoff	1,255,589	1,255,483	-106	0.01	1,171.313	1,171.341	+0.028	0.00
Action Time	144,086	143,902	-184	0.13	1,313.766	1,314.710	+0.944	0.07
Separation[2]	143,352	143,232	-120	0.08	1,315.747	1,316.169	+0.422	0.03
Nose Cap Deployment	142,774	142,752	-22	0.02	1,316.097	1,316.017	-0.080	0.01
Drogue Chute Deployment	142,759	142,751	-8	0.01	1,316.091	1,316.016	-0.075	0.01
Main Chute Line Stretch	142,731	142,708	-23	0.02	1,316.081	1,316.001	-0.080	0.01
Main Chute 1st Disreefing	142,720	142,688	-32	0.02	1,316.077	1,315.995	-0.082	0.01
Main Chute 2nd Disreefing	142,713	142,677	-36	0.03	1,316.075	1,315.991	-0.084	0.01
Nozzle Jettison	140,541	140,465	-76	0.05	1,305.771	1,305.781	+0.010	0.00
Splash Down	140,443	140,443	0	0.00	1,305.772	1,305.772	0.000	0.00

Notes:

1. Based on Mass Properties History Log Space Shuttle 3600004-LH, 9 January 1989 (TWR-17340).

2. The separation longitudinal center of gravity of 1,316.169 is 66% of the vehicle length.

Table 3.12

SEQUENTIAL MASS PROPERTIES PREDICTED/ACTUAL COMPARISONS
STS-30 Right Hand

Event	Weight (lb)				Longitudinal CG (in)			
	Predicted[1]	Actual	Delta	% Error	Predicted[1]	Actual	Delta	% Error
Pre-Ignition	1,256,695	1,256,695	0	0.00	1,171.305	1,171.305	0.000	0.00
Liftoff	1,256,060	1,256,041	-19	0.00	1,171.431	1,171.434	+0.003	0.00
Action Time	144,784	144,610	-174	0.12	1,315.322	1,315.556	+0.234	0.02
Separation[2]	144,050	143,997	-53	0.04	1,317.302	1,317.410	+0.108	0.01
Nose Cap Deployment	143,471	143,449	-22	0.02	1,317.657	1,317.582	-0.075	0.01
Drogue Chute Deployment	143,456	143,448	-8	0.01	1,317.652	1,317.582	-0.070	0.01
Main Chute Line Stretch	143,428	143,408	-20	0.01	1,317.642	1,317.569	-0.073	0.01
Main Chute 1st Disreefing	143,417	143,390	-27	0.02	1,317.638	1,317.563	-0.075	0.01
Main Chute 2ndDisreefing	143,410	143,379	-31	0.02	1,317.636	1,317.560	-0.076	0.01
Nozzle Jettison	141,157	141,180	+23	0.02	1,307.367	1,307.380	+0.013	0.00
Splash Down	141,149	141,149	0	0.00	1,307.368	1,307.368	0.000	0.00

Notes:

1. Based on Mass Properties History Log Space Shuttle 360H004-RH, 9 January 1989 (TWR-17341).

2. The separation longitudinal center of gravity of 1,317.410 is 66% of the vehicle length.

Table 3.13

PREDICTED/ACTUAL WEIGHT (lb) COMPARISONS

STS-30 LEFT HAND

QUARTER WEIGHT

Item	Minimum	Maximum	Predicted[3]	Actual	Delta	% Error	Notes
Inerts							
Prefire, Controlled		151,380	149,521	149,521	0	0.00	1
Propellant	1,103,730		1,106,703	1,106,703	0	0.00	1
Usable			1,105,844	1,106,021	+177	0.02	2
To Liftoff			534	555	+21	3.78	
Liftoff to Action			1,105,310	1,105,466	+156	0.01	2
Unusable			859	682	-177	25.95	
Action to Separation			669	605	-64	10.58	
After Separation			190	77	-113	146.75	
Slag			1,518	1,518	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 9 January 1989, Mass Properties History Log Space Shuttle 3600004-LH (TWR-17340).

Table 3.14

PREDICTED/ACTUAL WEIGHT (lb) COMPARISONS

STS-30 RIGHT HAND

HALF WEIGHT

Item	Minimum	Maximum	Predicted[3]	Actual	Delta	% Error	Notes
Inerts							
Prefire, Controlled		151,975	150,188	150,188	0	0.00	1
Propellant	1,103,560		1,106,477	1,106,477	0	0.00	1
Usable			1,105,618	1,105,784	+166	0.02	2
To Liftoff			534	556	+22	3.96	
Liftoff to Action			1,105,084	1,105,228	+144	0.01	2
Unusable			859	693	-166	23.95	
Action to Separation			669	548	-121	22.08	
After Separation			190	145	-45	31.03	
Slag			1,518	1,518	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 9 January 1989, Mass Properties History Log Space Shuttle 360H004-RH (TWR-17341).

REVISION

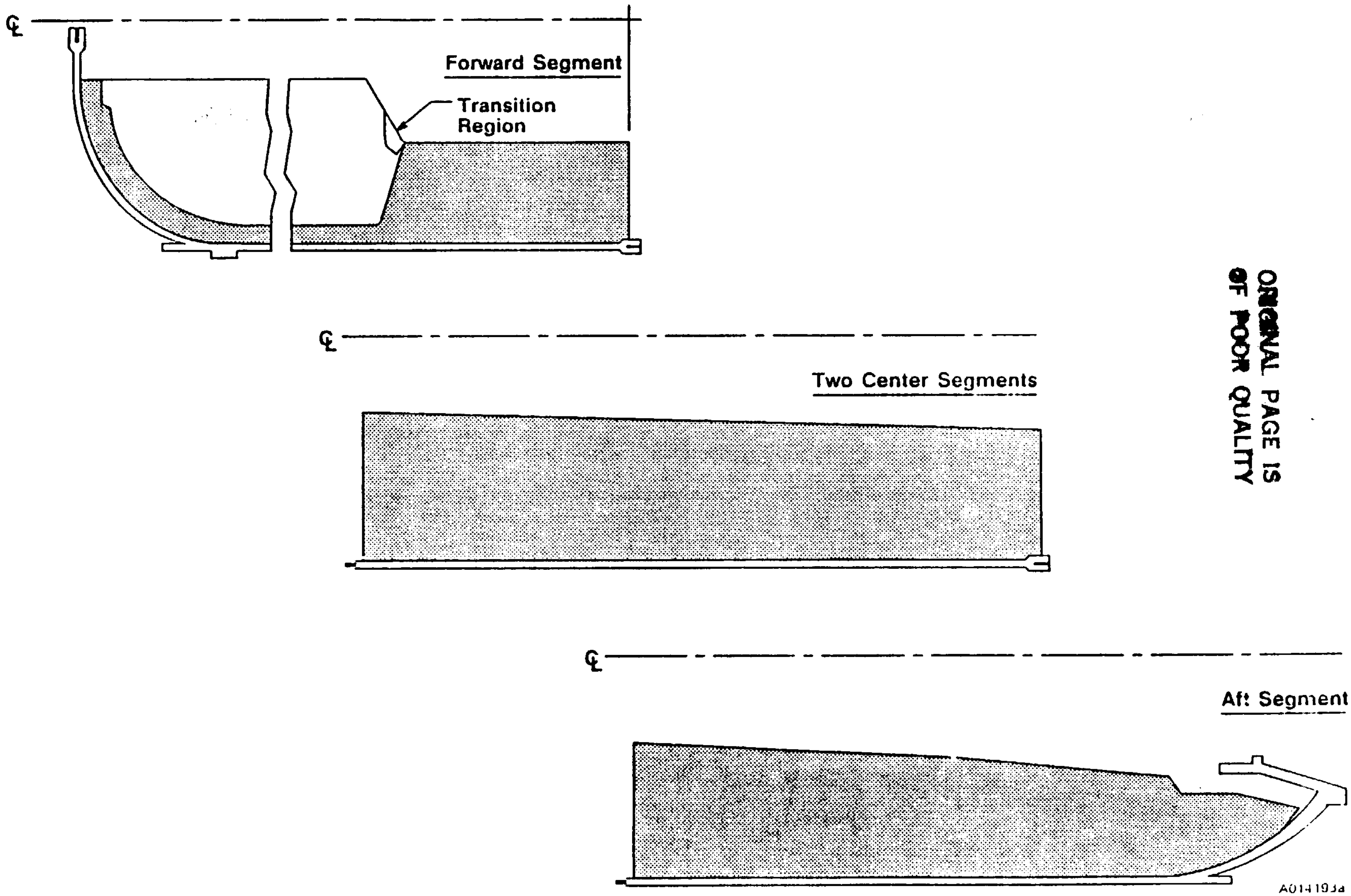


Figure 1.1 RSRM Propellant Grain Design Configuration

Figure 2.1

RSRM-4 RECONSTRUCTED VACUUM THRUST VS. TIME AT 71 DEG. F

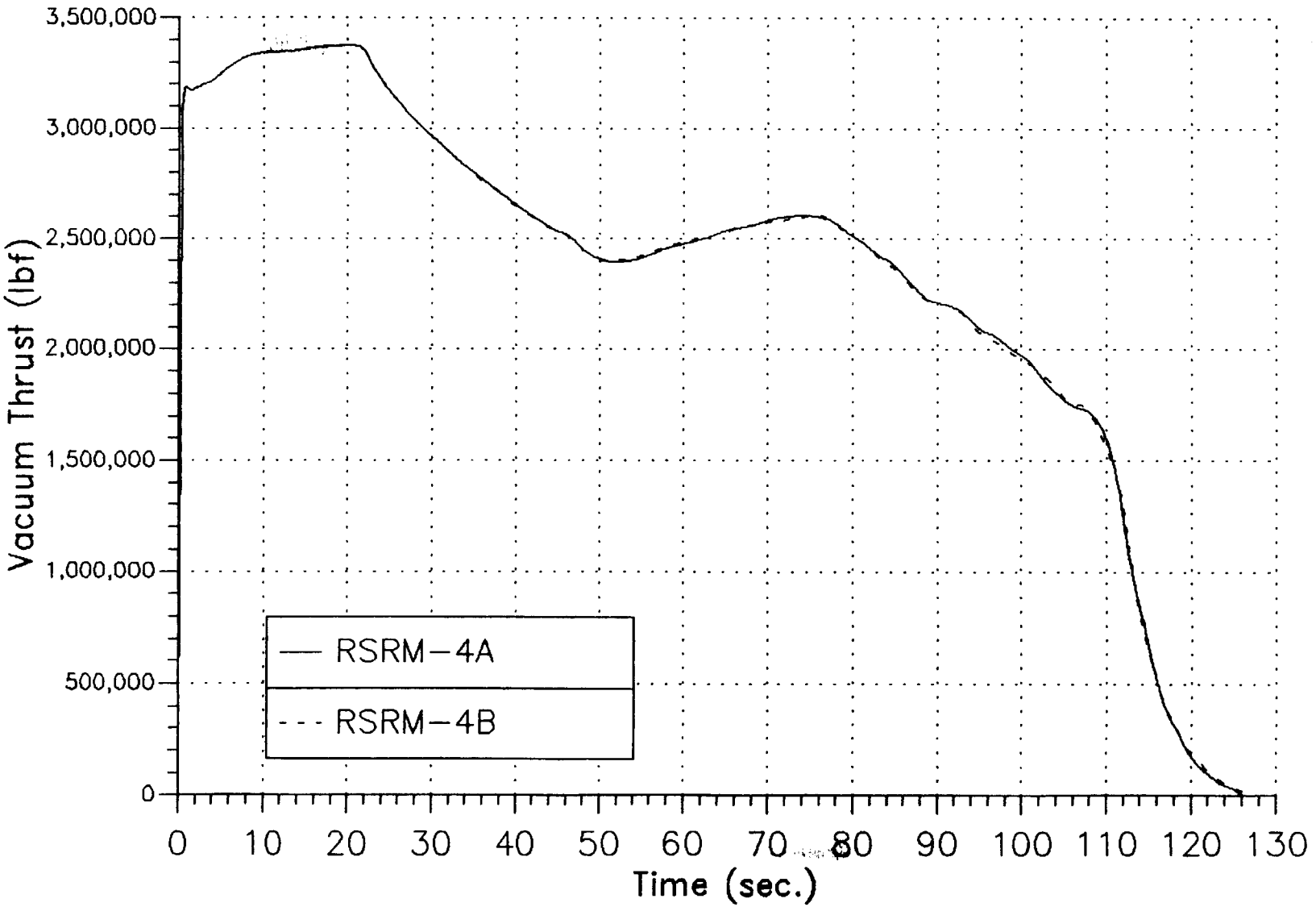


Figure 3.1

RSRM-4A PREDICTED AND RECONSTRUCTED VACUUM THRUST

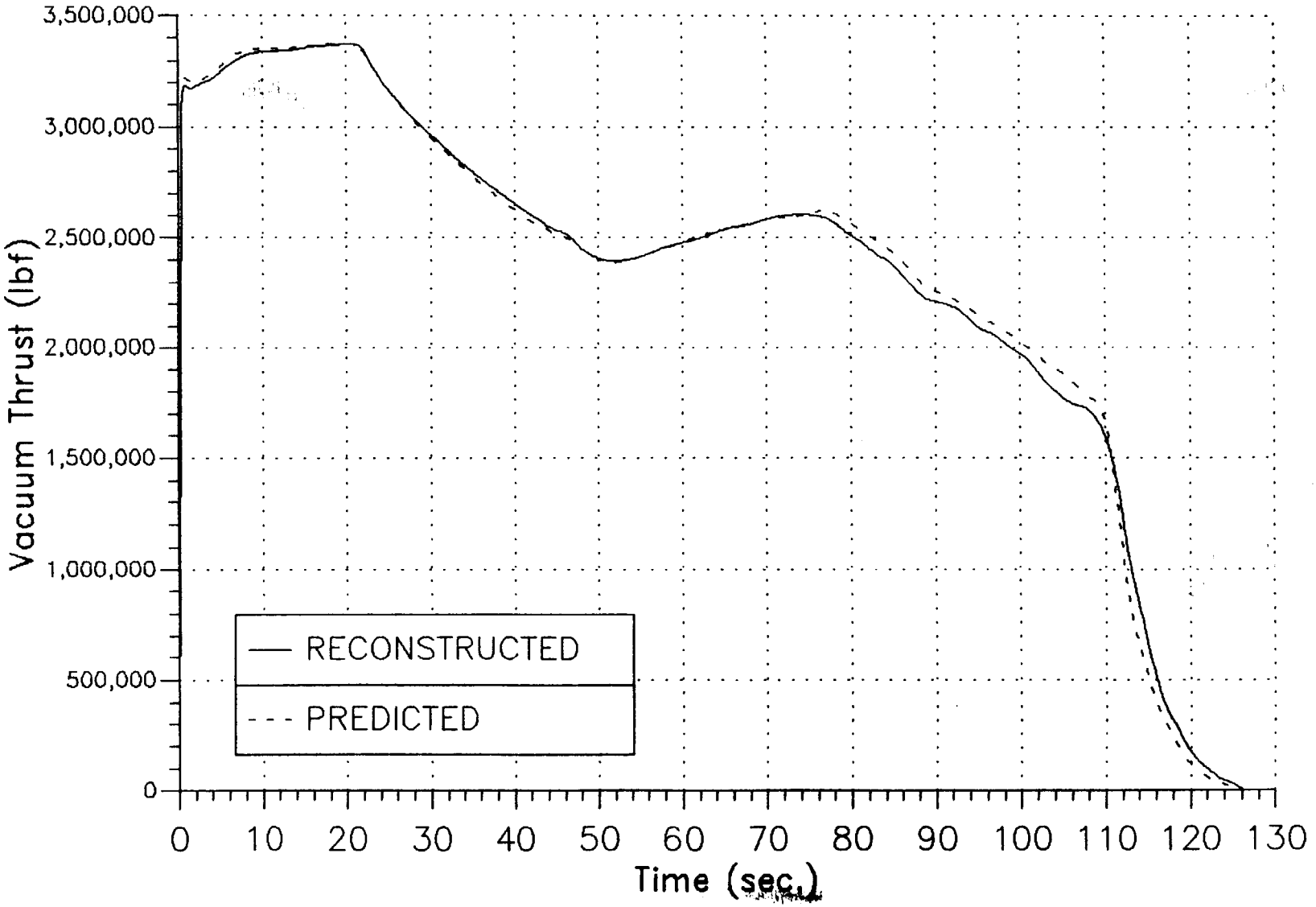


Figure 3.2

RSRM-4B PREDICTED AND RECONSTRUCTED VACUUM THRUST

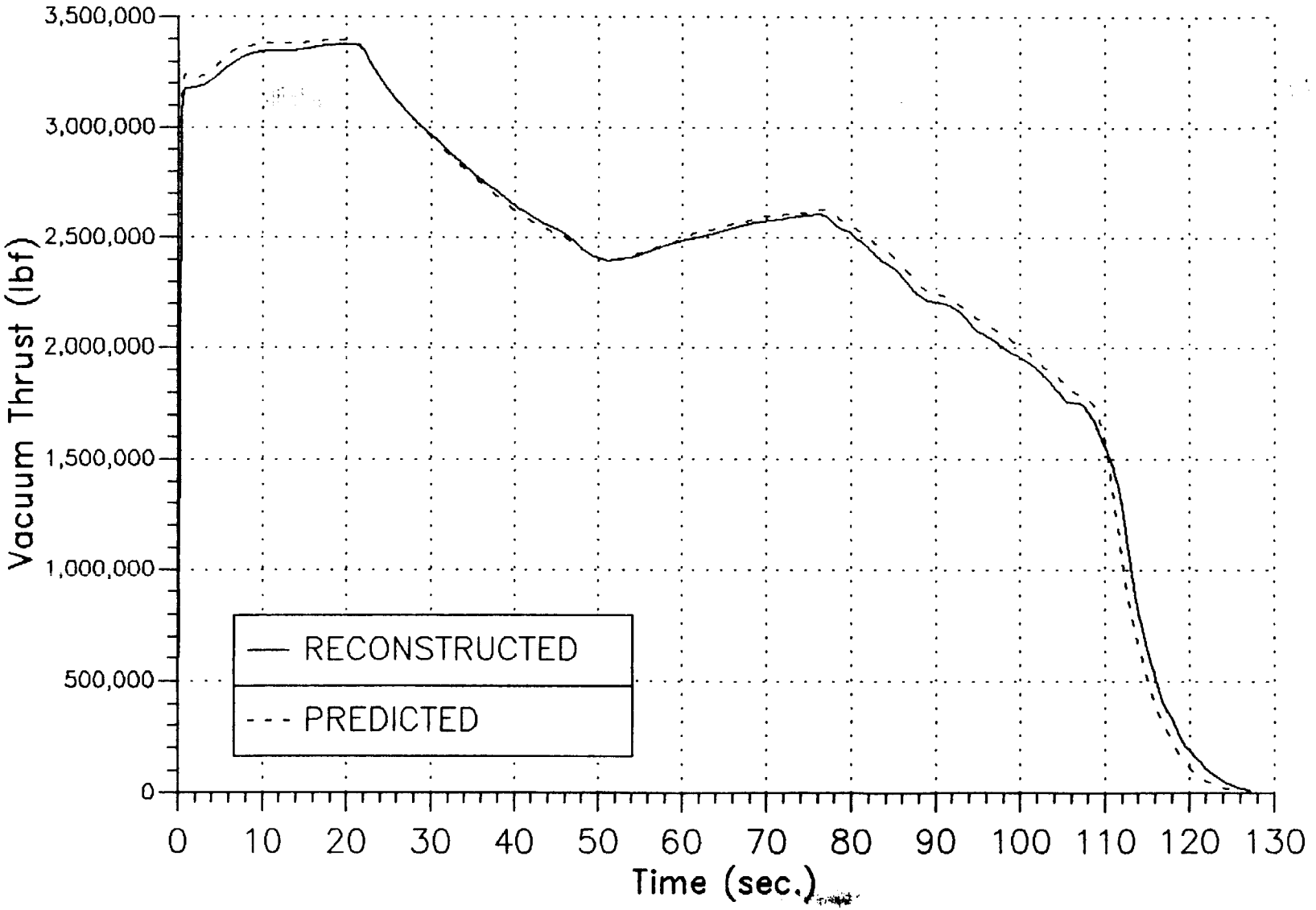


Figure 3.3

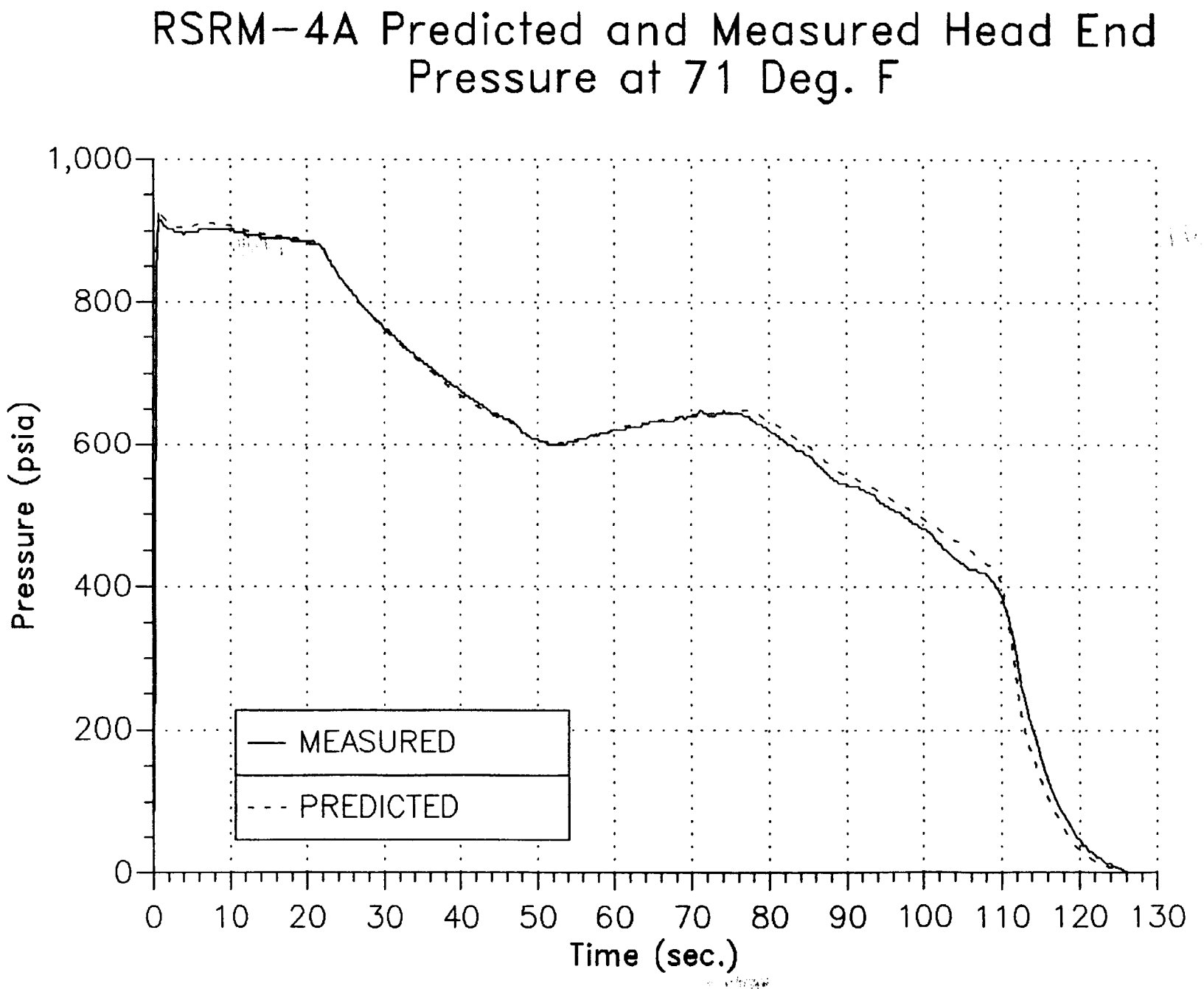

RSRM-4A Predicted and Measured Head End Pressure at 71 Deg. F
Pressure (psia)
1,000
800
600
400
200
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Time (sec.)
MEASURED
PREDICTED

Figure 3.4

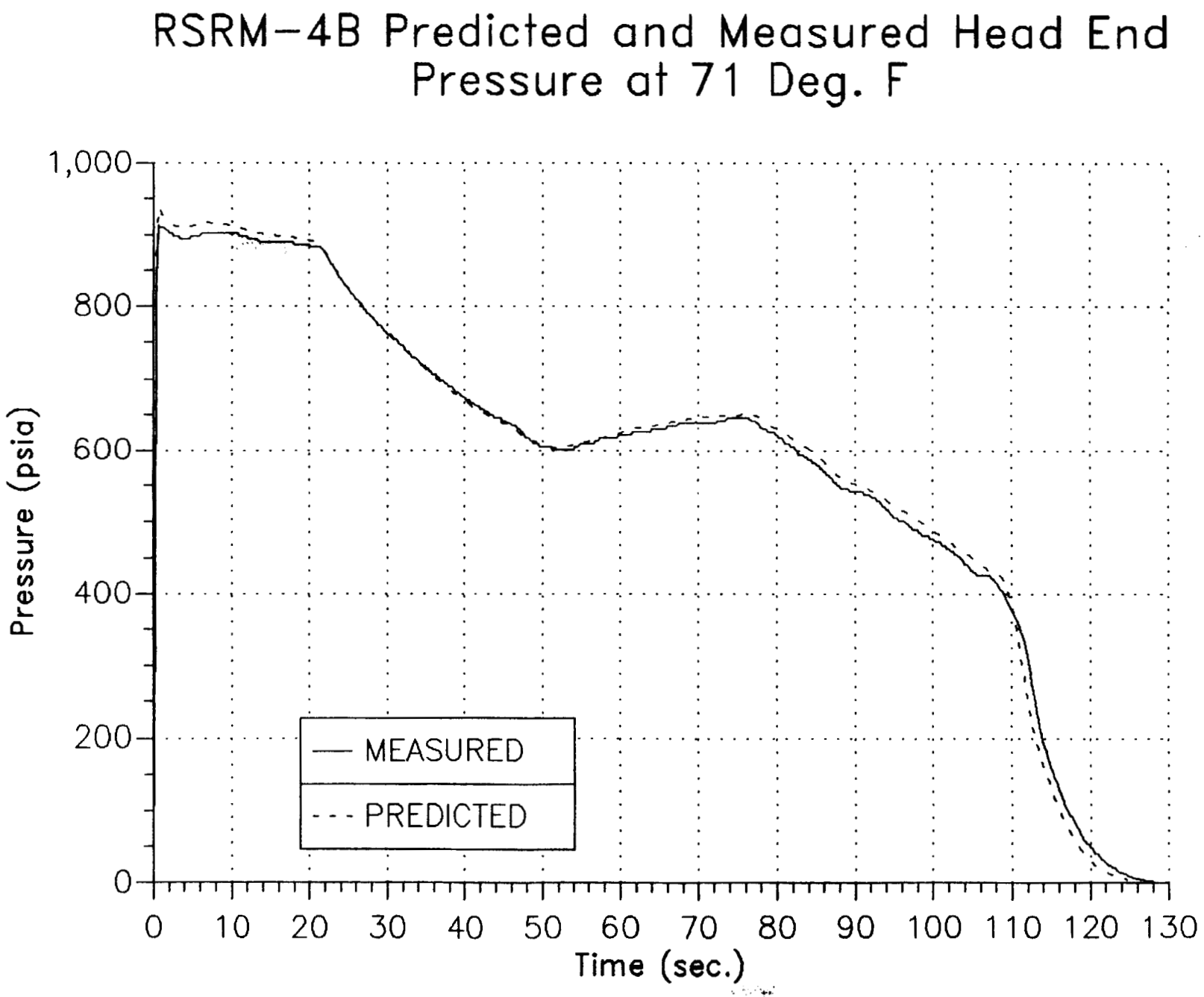

RSRM-4B Predicted and Measured Head End Pressure at 71 Deg. F
Pressure (psia)
1,000
800
600
400
200
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Time (sec.)
MEASURED
PREDICTED

Figure 3.5

RSRM–4A Performance Compared to HPM–RSRM Population Nominal

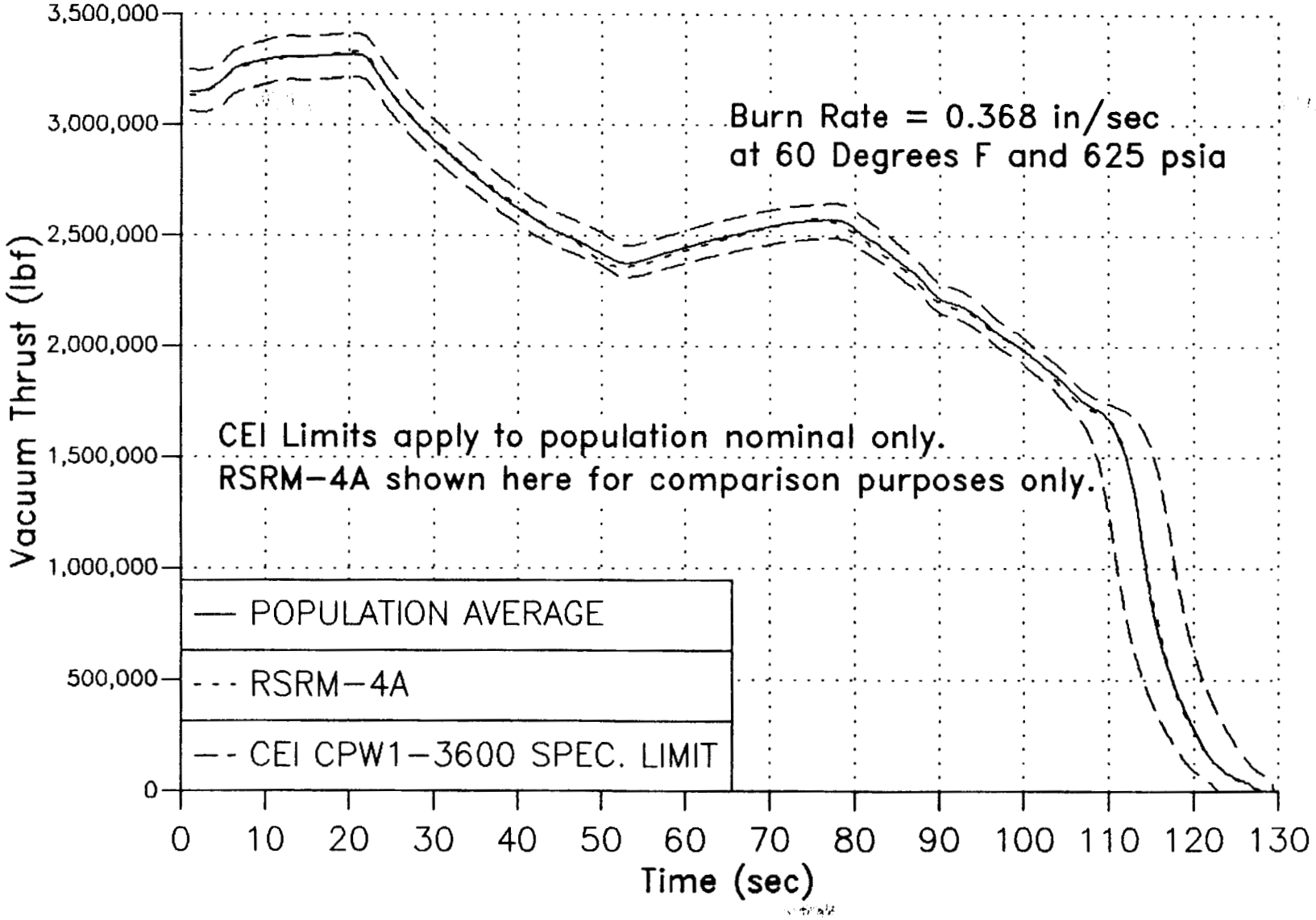


Figure 3.6

RSRM–4B Performance Compared to HPM–RSRM Population Nominal

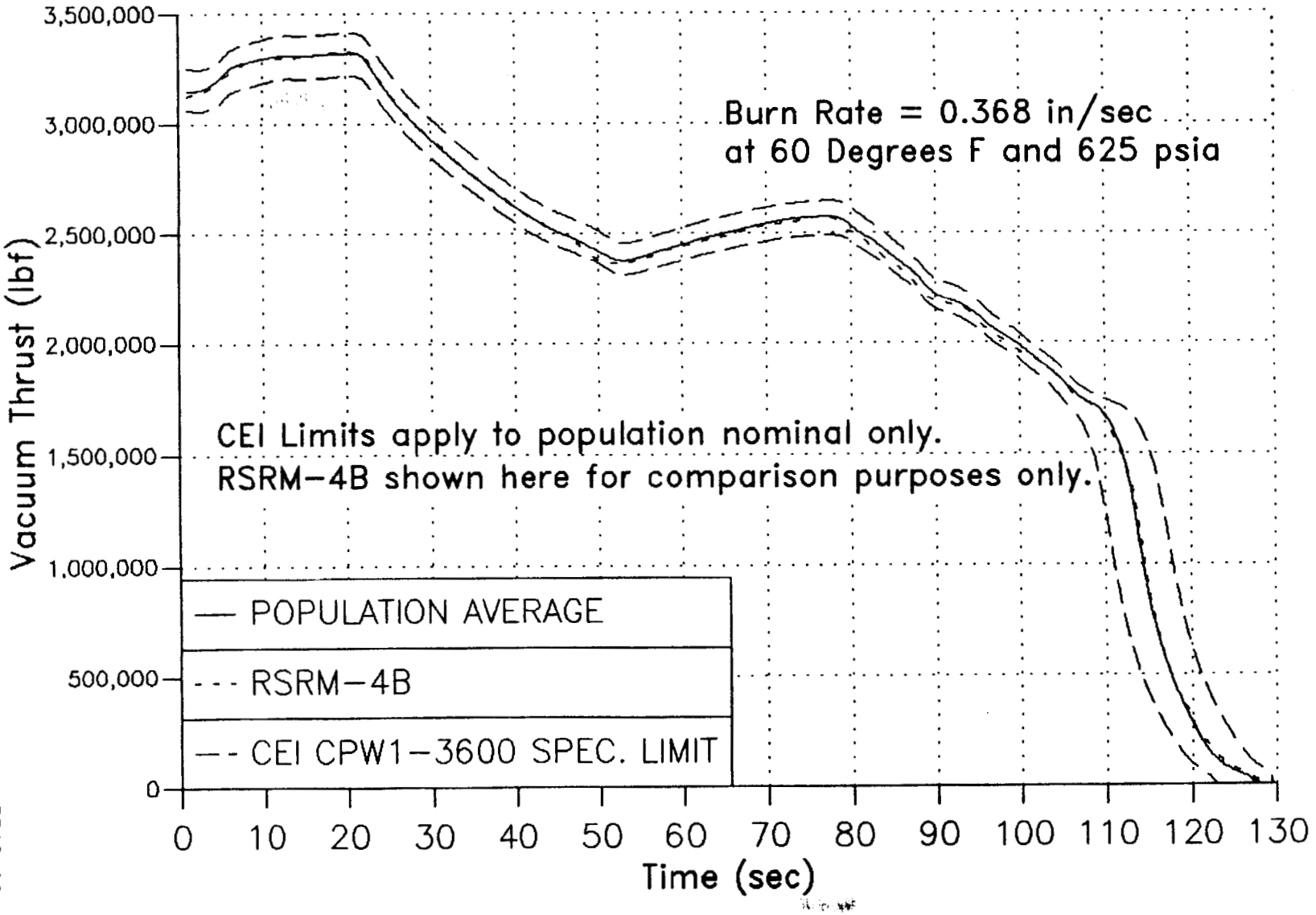


Figure 3.7

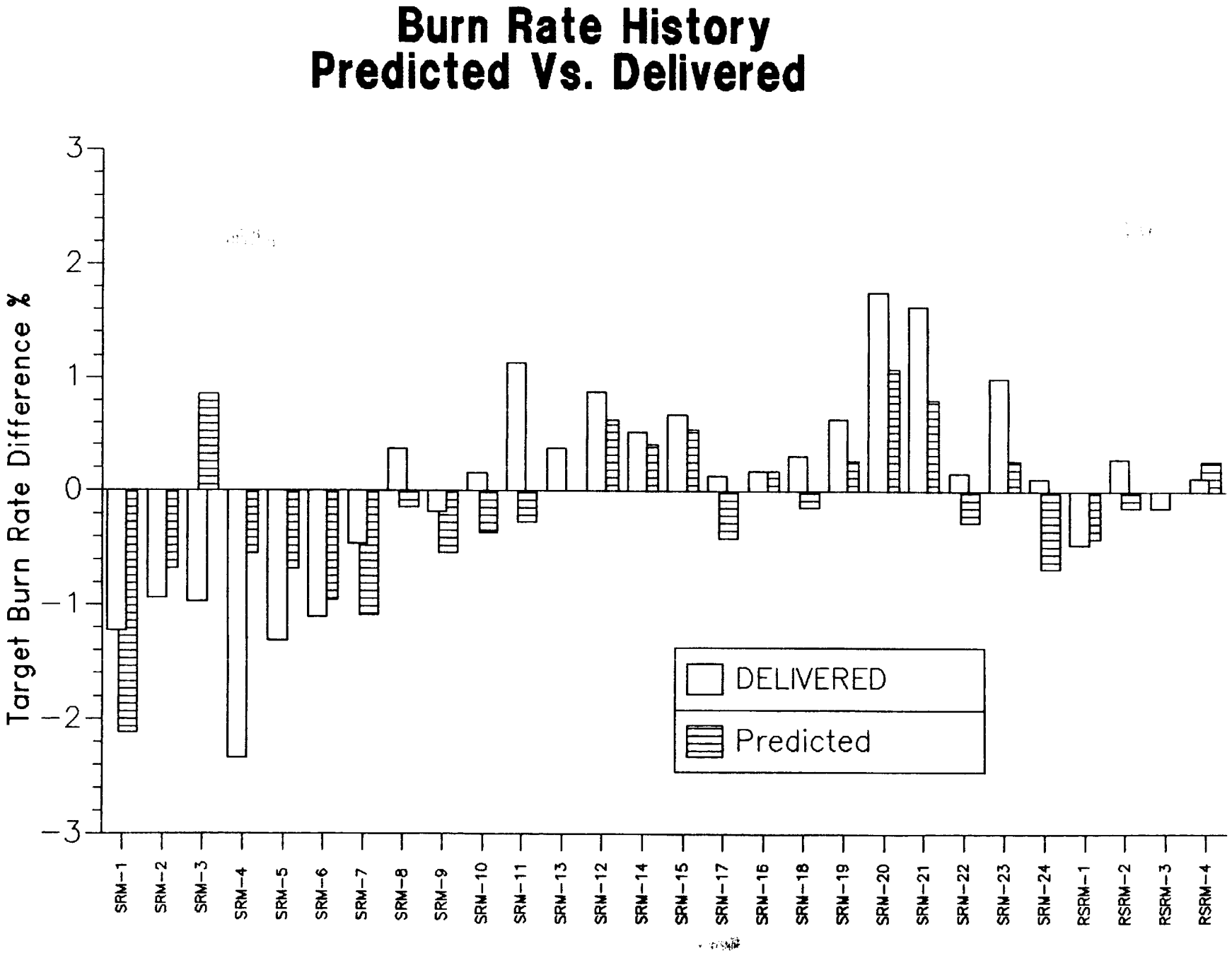

Burn Rate History
Predicted Vs. Delivered
Target Burn Rate Difference %
3
2
1
0
−1
−2
−3
DELIVERED
Predicted
SRM-1
SRM-2
SRM-3
SRM-4
SRM-5
SRM-6
SRM-7
SRM-8
SRM-9
SRM-10
SRM-11
SRM-13
SRM-12
SRM-14
SRM-15
SRM-17
SRM-16
SRM-18
SRM-19
SRM-20
SRM-21
SRM-22
SRM-23
SRM-24
RSRM-1
RSRM-2
RSRM-3
RSRM-4

Figure 3.8

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

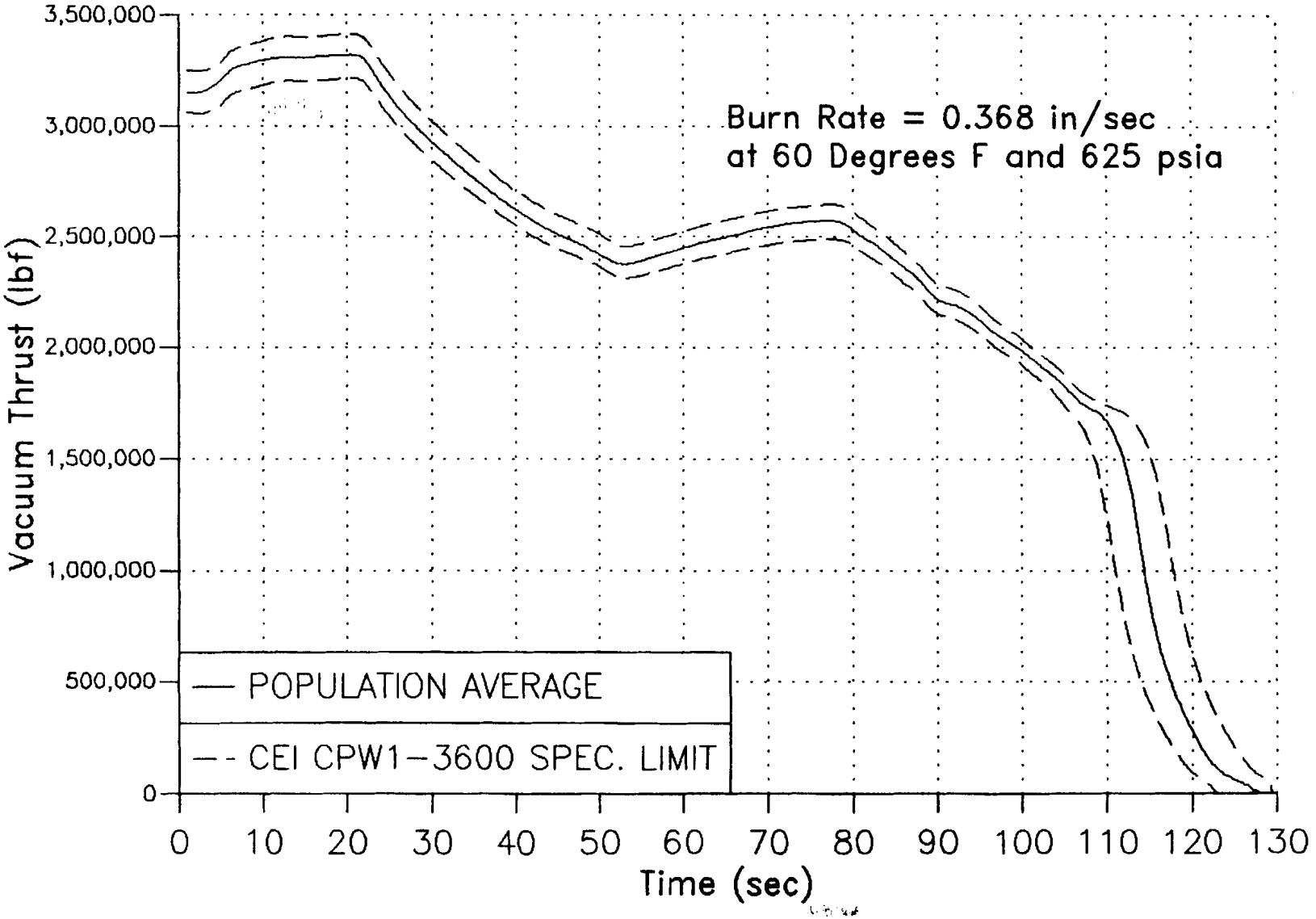


Figure 3.9

RSRM-4 Steady State Thrust Imbalance (Instantaneous)

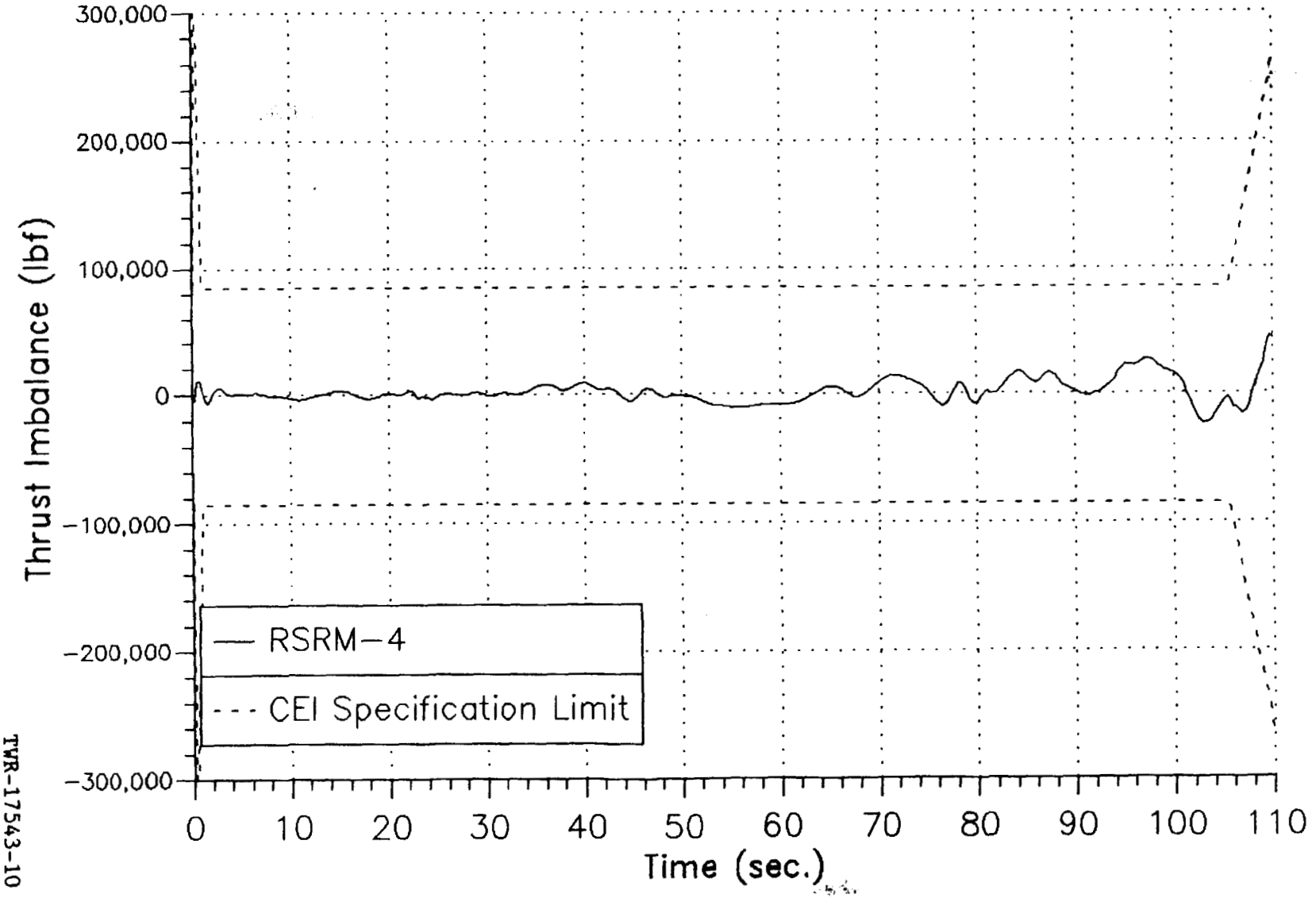


Figure 3.10

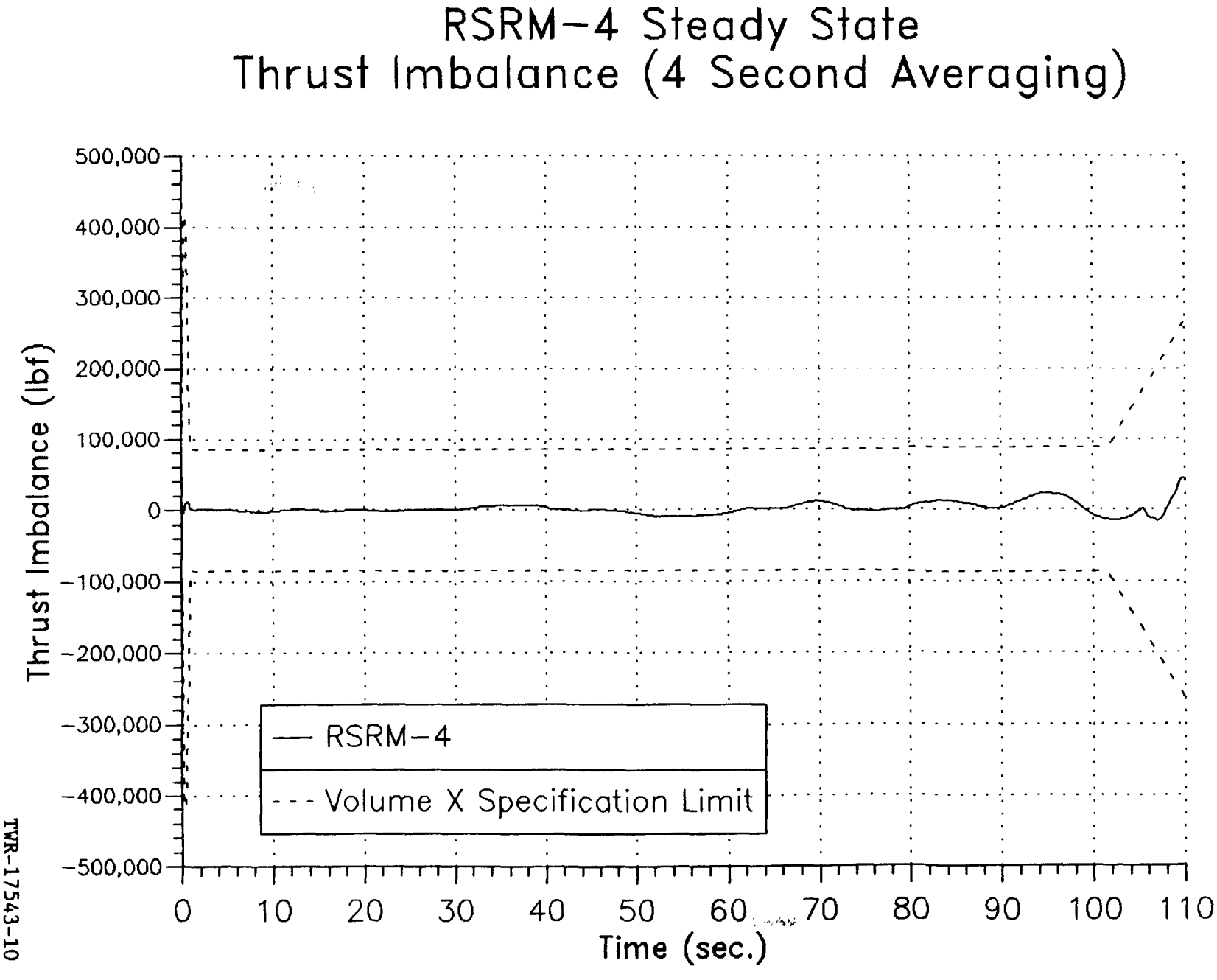
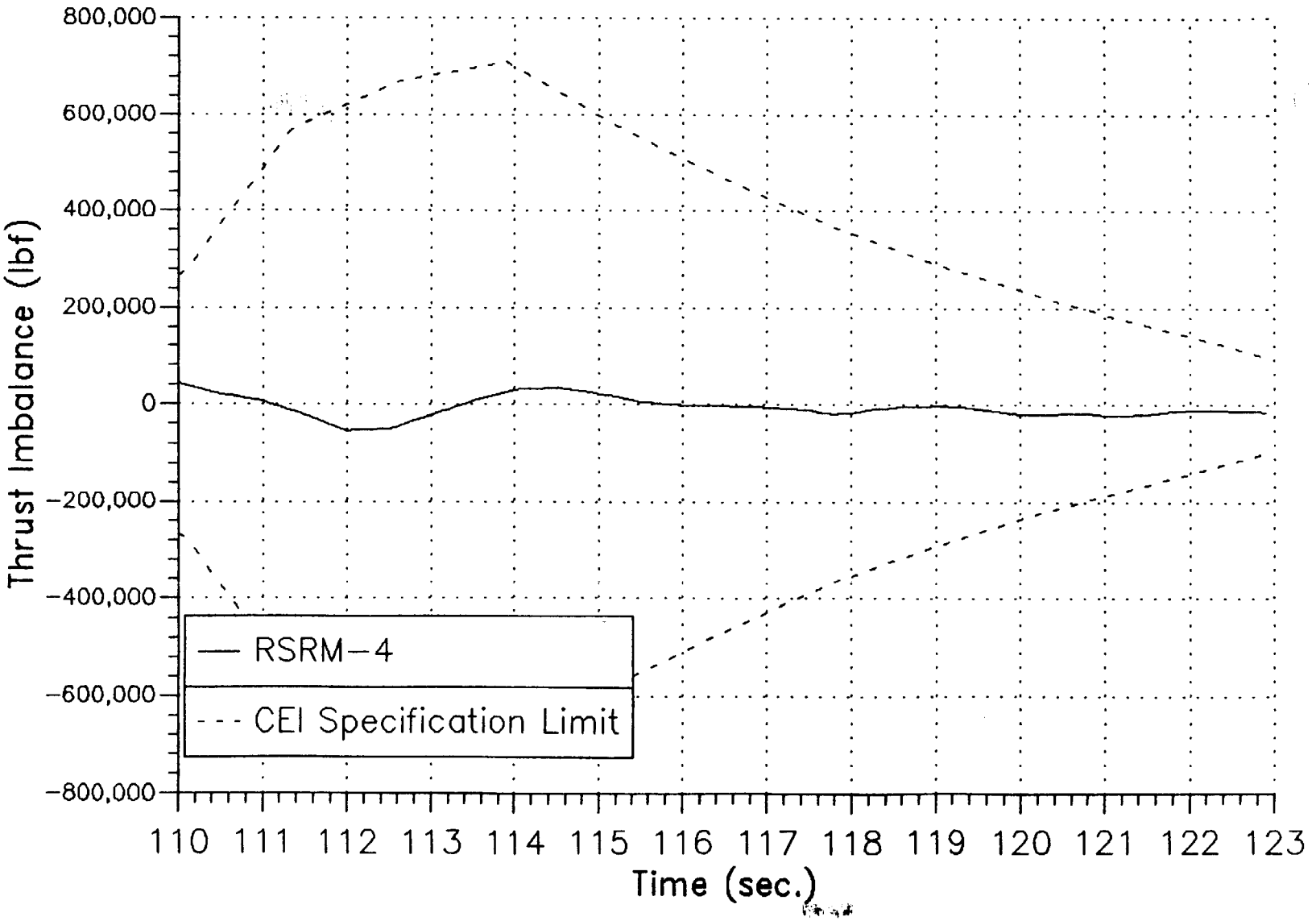

RSRM-4 Steady State
Thrust Imbalance (4 Second Averaging)
Thrust Imbalance (lbf)
500,000
400,000
300,000
200,000
100,000
0
-100,000
-200,000
-300,000
-400,000
-500,000
0
10
20
30
40
50
60
70
80
90
100
110
Time (sec.)
RSRM-4
Volume X Specification Limit

Figure 3.11

RSRM-4 Tail Off Thrust Imbalance (Instantaneous)



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