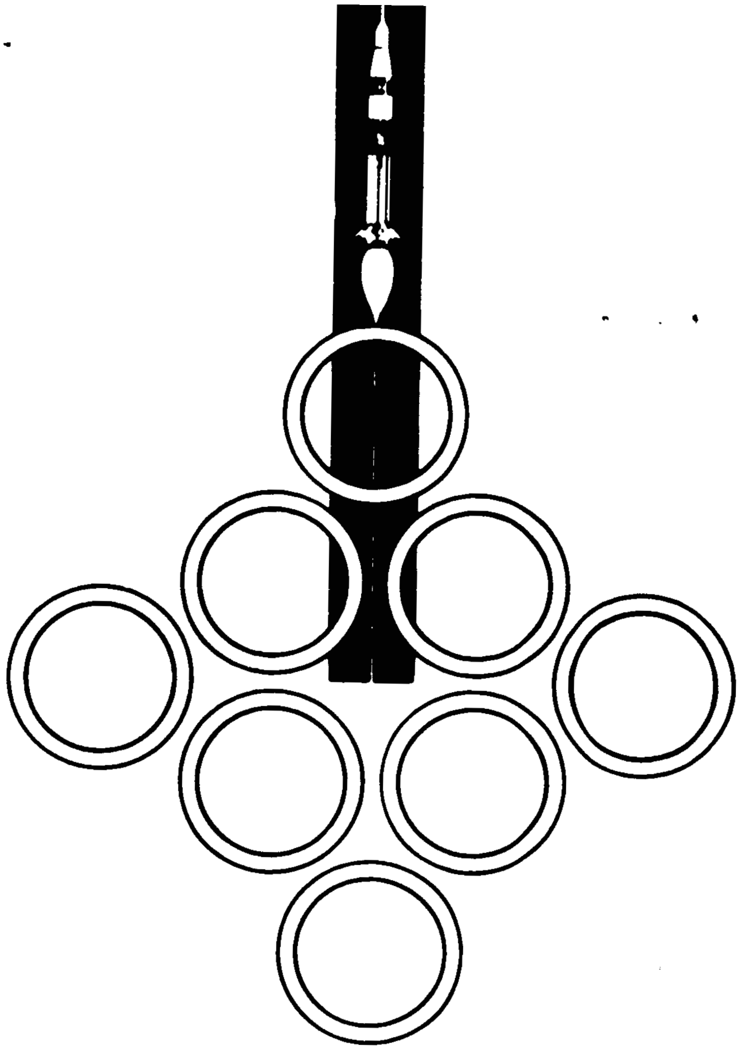

ENGINEERING DEPARTMENT

TECHNICAL REPORT

TR-P&VE-66-34

REVISION B

FINAL FLIGHT PERFORMANCE PREDICTION FOR SATURN AS-205 PROPULSION SYSTEM S-IB-5 STAGE

SATURN S-IB STAGE AND SATURN IB PROGRAM

SPACE DIVISION CHRYSLER CORPORATION

TECHNICAL REPORT

TR-P&VE-66-34
Revision B

FINAL FLIGHT PERFORMANCE PREDICTION FOR SATURN AS-205 PROPULSION SYSTEM S-IB-5 STAGE

April 1, 1968

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3000B-5-17-68

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ABSTRACT

Analysis of the revised final prediction data indicate that inboard and outboard engine cutoffs will occur approximately 140.61 seconds and 143.61 seconds after first motion, respectively. These times are based on defined fuel and LOX load specific weights, and stage propellant fill weights for the revised launch schedule for AS-205 (third quarter of 1968).

FOREWORD

This report presents the final flight performance prediction data for the Saturn AS-205 Propulsion System, S-IB-5 Stage, and is authorized by contract NAS8-4016 DRL 039, Revision B, Item 35.

The final prediction data were determined by simulating the first stage powered flight of Saturn AS-205 with the Mark IV computation procedure. The data presented in this revised report supersedes the information in the previous document, reference A.

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Section 1

SUMMATION

1.1 INTRODUCTION

The mission and launch date for the AS-205 vehicle used in the previous prediction (reference A) have been revised. This report (Revision B) presents the revised final flight performance prediction of the S-IB-5 propulsion system and discusses the data and methods used in making the prediction.

1.2 OBJECT

To present the predicted performance parameters of the S-IB-5 propulsion system.

1.3 CONCLUSIONS

Analyses of the final prediction data indicate that inboard and outboard engine cutoffs will occur approximately 140.61 seconds and 143.61 seconds after first motion, respectively. These times are based on the following assumptions:

a. A fuel load specific weight of 50.120 lbm/cu ft.

b. A LOX load specific weight of 70.499 lbm/cu ft.

c. A difference of 3 inches between the liquid levels in the center and the outboard LOX tanks at the time of inboard engine cutoff (IECO) signal.

d. Stage fill weights of 631,346 pounds of LOX and 277,217 pounds of fuel.

The propellant liquid level sensor actuation times and the corresponding engine cutoff sequence were determined from the prediction data.

Engine performance data from Rocketdyne single engine acceptance tests and the stage static tests (SA-34 and SA-35) were analyzed to determine the best engine characteristic data for the prediction. An analysis comparing past flight data with Rocketdyne acceptance test data and stage test data showed that, although stage test data more often predicted flight with greater accuracy, the Rocketdyne data showed more consistent deviations. By applying biasing factors to the Rocketdyne thrusts and flowrates, past flights could have been predicted with a much higher degree of accuracy than could have been determined by using either stage test or Rocketdyne data. Therefore, the engine data used for this prediction reflect Rocketdyne acceptance test data that has been adjusted in accordance with flight experience on the S-IB-1, S-IB-3, and S-IB-2.

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Section 2

DISCUSSION

2.1 VEHICLE DESCRIPTION

AS-205 will be the fifteenth Saturn vehicle, and the fifth of the Saturn IB series, to be flight tested. The AS-205 vehicle will consist of the S-IB-5 first stage, S-IVB-5 second stage, the S-IU-205 instrument unit, and an Apollo command/service module payload. The AS-205 is scheduled for launch during the third quarter of 1968.

2.2 PREDICTED PERFORMANCE

The Mark IV computer program was used to predict the flight performance of the S-IB-5 stage. The latest available table of H-1 engine influence coefficients was used in this prediction (reference B).

Rocketdyne recently revised the table of influence coefficients (gain table) that is used to predict and evaluate propulsion system flight performance. In addition to the gain table, Rocketdyne also revised their power balance math model of the H-1 engine which significantly affects the single engine acceptance test sea level data.

Other changes in criteria from that used in the last flight prediction released for S-IB-5 (reference A) are the launch date, aerodynamic and base drag, stage trajectory, and engine performance biasing factors. (See paragraph 2.2.3.)

2.2.1 Nominal Prediction

The Mark IV computer program printout containing detailed prediction data is available for review. Specific performance data were recorded on magnetic tapes B5 and B6, reels 0263 and 10214, respectively, and stored at the tape library of the Slidell Computer Center for use by CCSD Flight Mechanics (section 2783). A duplicate copy of the B6 tape (reel 8548), required by the Aero-Astrodynamics Laboratory (R-AERO-FMT) MSFC, was submitted to the Performance Analysis Section (R-P&VE-PPE) MSFC. A card deck was given to CCSD Weight Control Group (Section 2733) for evaluation.

Pertinent final weights data are presented in table I. Stage parameters, including predicted fill weights, ullage volumes, and engine cutoff times, are shown in table II. Vehicle thrust, specific impulse, fuel flowrate, LOX flowrate, and mixture ratio as functions of flight time referenced from first motion are shown in figures 1 through 5. LOX and fuel tank ullage pressures, ambient pressure, and LOX pump inlet specific weight, as functions of flight time, appear in figures 6 through 8. Representative individual engine performance curves for a typical outboard engine (position 1), as a function of flight time, are shown in figures 9 through 13. Average values

TABLE I

WEIGHT BREAKDOWN FOR AS-205 VEHICLE

	Miscellaneous (lb)	LOX (lb)	Fuel (lb)	Total (lb)
Consumption during ignition and hold down		10,723	3,135	13,858
Mainstage consumption		613,691	265,791	879,482
Consumption during inboard engine thrust decay*		768	1,383	2,151
Consumption during outboard engine thrust decay*		635	1,324	1,959
Propellant Residuals**		2,897	4,863	7,760
Gear box fuel consumption			721	721
GOX generated during flight		2,632		2,632
Ice	1,100			1,100
Initial LOX Tank pressurant	33			33
Hydraulic oil	28			28
Oronite (fuel additive for lubrication)	32			32
Initial weight of helium in the fuel tanks	5			5
Initial weight of nitrogen and helium in all spheres (for fuel container pressurization, S-IB stage purge, etc.)	90			90
Total upperstage weight plus S-IB stage dry weight	393,807			393,807
Total weight at ignition command	395,095	631,346	277, 217	1,303,658

* Thrust decay includes propellant below main valves that is not necessarily burned but ejected overboard after valves close.

** The fuel resiudal includes 1,000 lb for biasing purposes. The bias is available to provide equal propellant weight at the 3-sigma mixture ratio limits.

TABLE II

STAGE PARAMETERS FOR PREDICTED ENVIRONMENTAL CONDITIONS

Wind Speed (knots)	6.4
Ambient Temperature (degrees F)	71.0
Fuel Density (lb/ft^3)	50.12
LOX Density (lb/ft^3)	70.499
Average Thrust (kips)	1,742.845
Average Specific Impulse (sec)	281.275
Average LOX Flowrate (lb/sec)	4320.34
Average Fuel Flowrate (lb/sec)	1875.75
Average Mixture Ratio	2.3032
IECO (sec)	140.61
OECO (sec)	143.61
Fuel Load (lb)	277,217.0
LOX Load (lb)	631,346.0
Minimum Allowable Fuel Ullage (%)	2.0
Nominal Allowable LOX Ullage (%)	1.5
Fuel Ullage at Fill (%)	3.33
LOX Ullage at Fill (%)	1.50

for many of the parameters appear on these curves. The averages were calculated from first motion to IECO.

2.2.2 Propellant Usage

The stage fill weights shown in table II were determined for a LOX fill volume of 66,990.4 gallons with a specific weight of 70.499 lbm/cu ft, and a corresponding amount of fuel (required for simultaneous depletion of consumable propellants) at a specific weight of 50.12 lbm/cu ft. Propellant criteria appear in reference C.

Variations from the predicted fuel density will require adjustments to the predicted propellant loads to ensure simultaneous depletion of propellants. The required propellant loads for any fuel density are presented graphically in figure 14.

The fuel bias of 1,000 pounds is included in the fuel load to minimize propellant residuals if there are deviations from the predicted propellant mixture ratio. The fuel bias for this flight is the same as that used for all previous S-IB flights.

The LOX specific weight is based on a predicted wind velocity of 6.4 knots at launch time. The predicted fuel temperature was determined by using an estimated ambient air temperature for the third quarter of the year and an approximate 10°F chilldown due to LOX exposure. A sample of the fuel that will be used for S-IB-5 was not available for chemical analysis at the time of this prediction. The data presented are based on a mean fuel specific weight for the expected temperature in accordance with specification MIL-R-25576B.

All LOX in the tanks, sumps, and interchange lines (except approximately 3 gallons which will be trapped in the center tank sump) will be consumed. Approximately 75 gallons of the outboard engine suction line LOX volume will also be consumed if the predicted LOX starvation mode of OECO occurs. The remaining LOX in the suction line is considered as unusable propellant and is shown as LOX residual in table II.

It is predicted that the fuel level at the end of outboard engine thrust decay will be approximately at the bottom of the containers. The fuel in the sump, interchange lines, and the suction lines is shown as residual in table II.

A portion of the predicted fuel residual is the 1000-pound fuel bias which is available for consumption prior to IECO. Approximately 850 pounds more of the residual can be consumed prior to OECO if a significantly lower than predicted consumption mixture ratio is experienced. The difference in consumption ratios would result in a simultaneous OECO signal from the thrust OK pressure switches and the fuel depletion probes which are located approximately 11 inches below the theoretical bottom of fuel tanks F-2 and F-4. If the predicted performance occurs, this total of 1850 pounds of fuel will not be consumed.

The S-IB-5 stage has a 19-inch diameter orifice in the center tank sump. This orifice will cause the LOX liquid level in the center tank to be approximately 3 inches above that of the outboard tanks at IECO. The liquid level height differential between the center LOX tank and outboard LOX tank is important in predicting stage shutdown criteria with a LOX pump starvation cutoff because it established the amount of LOX remaining for consumption at the time of IECO. A larger than expected liquid level differential will cause an earlier than predicted liquid level sensor actuation; consequently, an earlier IECO and later OECO will result. A smaller than expected differential will cause the converse. Small deviations from the predicted height differentials are not too significant in overall stage performance because the total impulse will be approximately the same as predicted, even though engine cutoff times will be different.

2.2.3 Engine Performance

Engine performance data were analyzed from revised Rocketdyne acceptance test data logs and their relationship with actual flight data for the flights of S-IB-1, S-IB-2, and S-IB-3. This study revealed that the Rocketdyne acceptance test data offered consistent correlation with the flight data. The average differences between the flight data and the Rocketdyne test data for the first three S-IB flights were determined and used to adjust the Rocketdyne data for this prediction. The Rocketdyne data were adjusted by the following multipliers: thrust, 1.00727; chamber pressure, 1.00650; RPM, 1.00521; LOX flowrate, 1.01161; and, fuel flowrate, 1.00724. The predicted individual engine flight data reduced to sea level and rated pump inlet conditions at 30 seconds after first motion are shown in table IV and were used to predict flight performance. A comparison of the previous prediction data with the acceptance test data and revised prediction data are shown in table III.

The previous prediction data is based on Rocketdyne PAST-073 engine data for the S-IB-5 stage, and flight biasing factors determined from vehicles AS-201, AS-202, and AS-203 using PAST-073 data. The revised prediction data used herein reflect Rocketdyne PAST-076 engine data for S-IB-5 and flight biasing factors generated from AS-201, AS-202, and AS-203 using PAST-076 data (reference D).

Since the last prediction (reference A), the power balance computer program (PAST-073) has been revised to reflect the results of a fuel temperature study (reference E). The engine acceptance test data, reduced to rated pump inlet conditions with the new math model (PAST 076), produced tags which are significantly different from the PAST-073-reduced data. Further revisions may prove necessary once the experience gained through the flight of AS-204 has been incorporated into the biasing factors.

The flight multipliers account for the performance differences noted at 30 seconds. In addition, previous S-IB flights have exhibited a shift throughout flight in engine performance referenced to sea level and rated pump inlet conditions. Included in this shift was a buildup to quasi-stable conditions at approximately 30 seconds with a slower buildup thereafter. The final prediction for AS-205 includes a performance shift equivalent to that noted in previous S-IB flight performance. Figure 16 shows this power level shift as a percentage of the predicted 30-second sea level thrust. The flight multipliers were used only to shift the curve upward. The shape of the curve was determined from analysis of the first three S-IB flights.

2.2.4 Engine Cutoff Criteria

The time base two (T_2) cutoff sequencing will be initiated when any one of the four liquid level sensors is uncovered. The predicted actuation time is 137.41 seconds after first motion. Liquid level sensors are located in fuel tanks F-2 and F-4 and LOX tanks 0-2 and 0-4. IECO will be signaled by the launch vehicle digital computer (LVDC) 3.2 seconds after initiation of the T_2 cutoff sequence.

The OECO signal can be given by the thrust OK pressure switches in any one of the outboard engines or by one of the fuel depletion probes located in the sumps of fuel tanks F-2 and F-4. The predicted performance is based on the assumption that LOX pump starvation of two of the four outboard engines will occur 3 seconds after the IECO signal, and that the OECO signal will be given by deactuation of the thrust OK pressure switches.

TABLE III

SUMMARY OF SEA LEVEL TEST DATA FOR THE S-IB-5 STAGE ENGINES

Source	Parameter	Rocketdyne Engine Logs from PAST-73 Program	Previous Prediction	Rocketdyne Engine Logs from PAST-076 Program	Prediction*
Engine H-7066 Position 1	Thrust (kips) Specific Impulse (sec) Mixture Ratio	201.53 263.43 2.2308	203.10 262.60 2.2512	200.75 262.91 2.2314	202.21 262.49 2.2511
Engine H-7067 Position 2	Thrust (kips) Specific Impulse (sec) Mixture Ratio	197.60 262.98 2.2394	199.14 262.16 2.2599	196.20 261.68 2.2408	197.63 261.26 2.2606
Engine H-7068 Position 3	Thrust (kips) Specific Impulse (sec) Mixture Ratio	199.56 263.58 2.2283	201.11 262.76 2.2487	198.44 263.03 2.2293	199.88 262.26 2.2490
Engine H-7069 Position 4	Thrust (kips) Specific Impulse (sec) Mixture Ratio	195.29 262.10 2.2636	196.81 261.28 2.2843	195.31 261.87 2.2636	196.73 261.45 2.2836
Engine H-4063 Position 5	Thrust (kips) Specific Impulse (sec) Mixture Ratio	197.04 263.38 2.2205	198.57 262.56 2.2409	196.44 262.84 2.2212	197.87 262.43 2.2408
Engine H-4064 Position 6	Thrust (kips) Specific Impulse (sec) Mixture Ratio	199.06 262.98 2.2181	200.61 262.16 2.2384	198.34 262.40 2.2187	199.78 261.98 2.2383
Engine H-4065 Position 7	Thrust (kips) Specific Impulse (sec) Mixture Ratio	196.90 262.19 2.2262	198.44 261.37 2.2466	196.18 261.62 2.2270	197.61 261.20 2.2467
Engine H-4066 Position 8	Thrust (kips) Specific Impulse (sec) Mixture Ratio	198.82 263.51 2.2316	200.37 262.69 2.2520	197.57 262.56 2.2328	199.01 262.14 2.2526
Average Engine	Thrust (kips) Specific Impulse (sec) Mixture Ratio	198.22 263.02 2.2323	199.77 262.20 2.2528	197.40 262.36 2.2331	198.84 261.90 2.2528

* See section 2.2.3

TABLE IV

SEA LEVEL PERFORMANCE OF S-IB-5 STAGE AT 30-SECONDS FLIGHT TIME

Parameter	Nominal Value	Engine H-7066 Pos. 1	Engine H-7067 Pos. 2	Engine H-7068 Pos. 3	Engine H-7069 Pos. 4	Engine H-4063 Pos. 5	Engine H-4064 Pos. 6	Engine H-4065 Pos. 7	Engine H-4066 Pos. 8	Vehicle Parameters
Engine Thrust (kips)	200.00	202.21	197.63	199.88	196.73	197.87	199.78	197.61	199.01	1,585.27*
Engine Specific Impulse (sec)	262.88	262.49	261.26	262.26	261.45	262.43	261.98	261.20	262.14	260.80**
Chamber Pressure (psia)	689.31	699.45	683.54	692.74	678.91	681.77	688.05	684.27	686.18	
Engine LOX Flowrate (lbm/sec)	525.27	533.39	524.44	527.55	523.30	521.34	527.08	523.51	525.76	4,206.4
Engine Fuel Flowrate (lbm/sec)	235.54	236.95	231.99	234.57	229.15	232.66	235.48	233.01	233.40	1,872.2**
Engine Mixture Ratio	2.2301	2.2511	2.2606	2.2490	2.2836	2.2408	2.2383	2.2467	2.2526	2.2468**
Turbopump Speed (rpm)	6,716.5	6,794.9	6,655.7	6,734.5	6,644.3	6,626.8	6,725.3	6,636.8	6,631.4	
Engine Throat Area (in^2)	204.35	204.35	204.35	204.35	204.35	204.35	204.35	204.35	204.35	
Engine Expansion Ratio	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	

* Thrust along longitudinal axis

** Includes fuel used as lubricant

The T_2 sequence is expected to start 137.41 seconds after first motion. Time base two (T_2) sequencing is summarized below:

T_2 + 0.0 sec - LVDC activated by LSA or back-up timer.

T_2 + 3.2 sec - IECO signal given by LVDC.

T_2 + 4.7 sec - Outboard engine thrust OK pressure switches grouped.

T_2 + 5.7 sec - Fuel depletion sensors armed.

T_2 + 6.2 sec - OECO signal expected due to LOX starvation.

This sequence was determined for the predicted performance with the fuel and LOX liquid level sensors located as shown in Figure 15. The fuel sensor locations are based on predicted fuel levels for the above time base two sequence. The locations are referenced from theoretical tank bottoms. The sequence separates thrust OK pressure switch grouping from fuel depletion sensor arming to minimize the possibility of OECO caused by a premature sensor signal.

2.2.5 Dispersions

In addition to the nominal prediction, five flights were simulated to show the effects of various propulsion performance dispersions. These flights consist of fuel density dispersions due to ± 3-sigma prelaunch ambient air temperature deviations, LOX density variations caused by ± 3-sigma prelaunch wind speed deviations, and the effect of a lower than expected consumption ratio on stage performance. Data obtained from the additional flight simulations are shown in table V, based on data contained in Reference C. The results of these simulations are available from the following tapes:

Case	A-5 Tape Reel No.	B-5 Tape Reel No.	B-6 Tape Reel No.	B-6 Copy Reel No.
Nominal	6484	0263	10214	8548 (File 1)
- 3-sigma ambient temperature	7214	6614	6256	8548 (File 2)
+ 3-sigma ambient temperature	10665	10833	10258	8548 (File 3)
- 3-sigma wind speed	7105	4192	4207	8548 (File 4)
+ 3-sigma wind speed	3436	4615	1347	8548 (File 5)
- 3-sigma Mixture Ratio Case	7294	2362	0289	0561
Delivered to Section No.	2733	2783	Library	R-P&VE-PPE (MSFC)

TABLE V

STAGE PARAMETERS FOR VARIOUS ENVIRONMENTAL CONDITIONS

Parameter	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6*
Wind Speed (probability limit) (knots)	(+3) -290.66	(-3) -292.29	Nominal -291.56	Nominal -291.56	Nominal -291.56	Nominal -291.56
Ambient Temperature (probability limit) (degrees F)	Nominal	Nominal	Nominal	(+3)	(-3)	Nominal
Fuel Temperature	71	71	71	81	58	71
Fuel Density (lb/ft^3)	50.12	50.12	50.12	49.87	50.45	50.12
LOX Density (lb/ft^3) (Vents Open)	70.337	70.581	70.499	70.499	70.499	70.499
Average Thrust (kips)	1735.194	1749.493	1742.845	1756.252	1725.170	1742.804
Average Specific Impulse (sec)	281.111	281.423	281.275	281.601	280.831	281.264
Average LOX Flowrate (lb/sec)	4298.96	4338.75	4320.34	4357.10	4271.92	4311.98
Average Fuel Flowrate (lb/sec)	1873.57	1877.70	1875.79	1879.47	1871.08	1884.26
Average Mixture Ratio	2.29447	2.31061	2.30315	2.31819	2.28306	2.28835
IECO (sec)	141.265	140.030	140.609	139.367	142.278	140.480
OECO (sec)	144.302	143.059	143.609	142.367	145.278	144.228
Fuel Load (lb)	277217	277217	277217	275409	279707	277217
LOX Load (lb)	631076	631465	631346 ✓	631346	631346	631346
Minimum Allowable Fuel Ullage (%)	2.0	2.0	2.00	2.00	2.00	2.00
Nominal Allowable LOX Ullage (%)	1.5	1.5	1.50	1.50	1.50	1.50
Fuel Ullage at Fill (%)	3.33	3.33	3.33	4.03	3.65	3.88
LOX Ullage at Fill (%)	1.30	1.60	1.50	1.50	1.50	1.50

* Case 6 represents the minus three sigma mixture ratio dispersion case.

As a result of a premature fuel depletion cutoff on S-IB-1, the fuel level sensor heights were adjusted by an amount which makes approximately 850 pounds of fuel available for consumption after IECO and prior to OECO if a significantly lower than predicted consumption ratio is experienced. Because of the possible consumption of this fuel, the time between IECO and OECO can be as much as four seconds and would result in significant differences in S-IB-5 flight performance from that predicted. Since the nominal performance prediction assumes a LOX starvation mode OECO with a 3-second differential between IECO and OECO, the possibility of a 4-second differential must be accounted for in the propulsion performance dispersions.

The correct dispersion to include this effect is in the engine mixture ratio (EMR) residual propellant dispersion. The data on the dispersion tape reflects an effective shift of -0.68 per cent in propellant mixture ratio while holding thrust and specific impulse values the same as for the nominal case. The effective mixture ratio shift accounts for consumption of the 1000-pound fuel bias prior to IECO and an additional 850 pounds of fuel which is available prior to OECO; as a result, 1850 pounds of additional fuel will be consumed with the nominal LOX consumption.

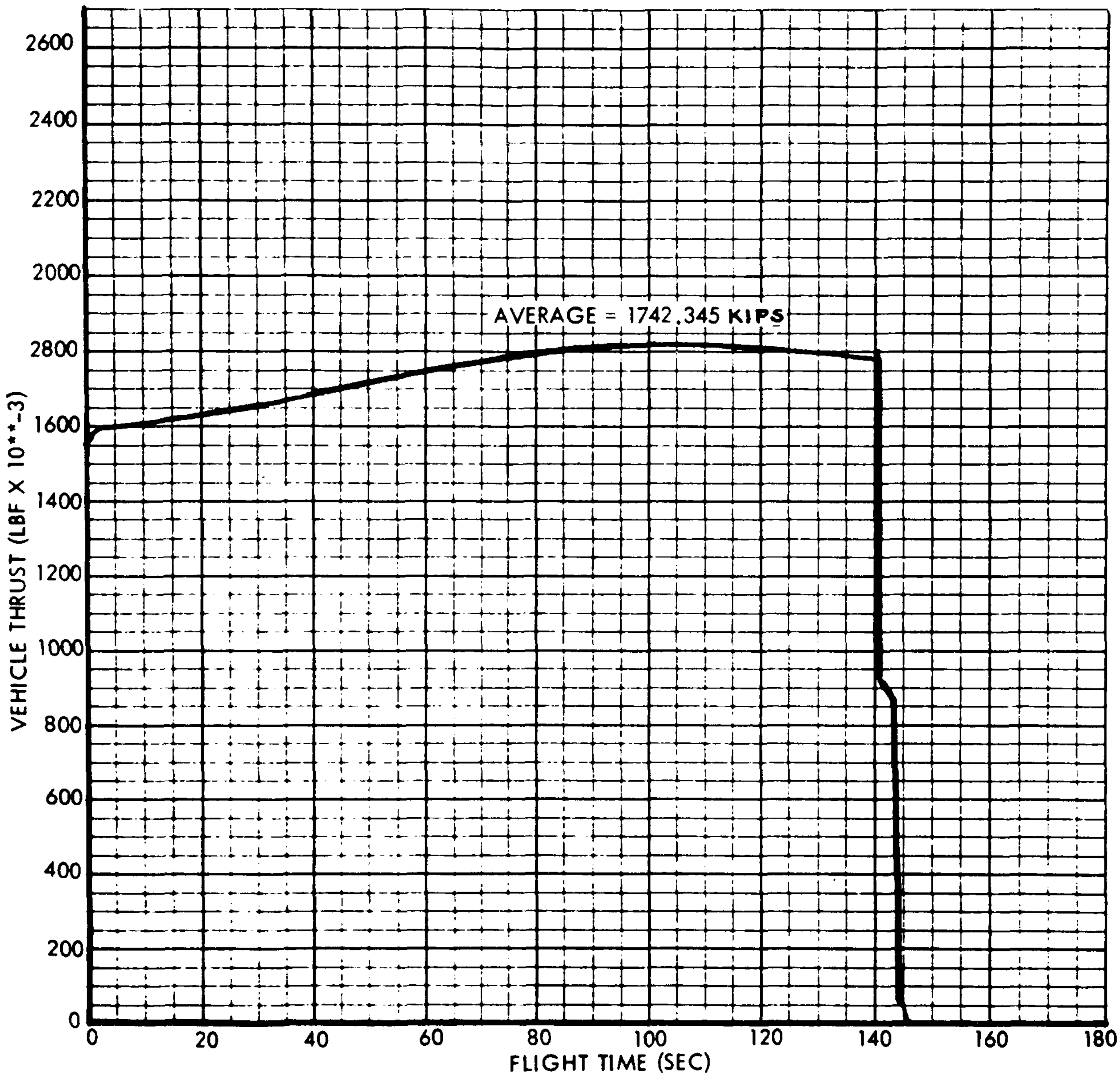

Figure 1. Vehicle Longitudinal Thrust versus Flight Time

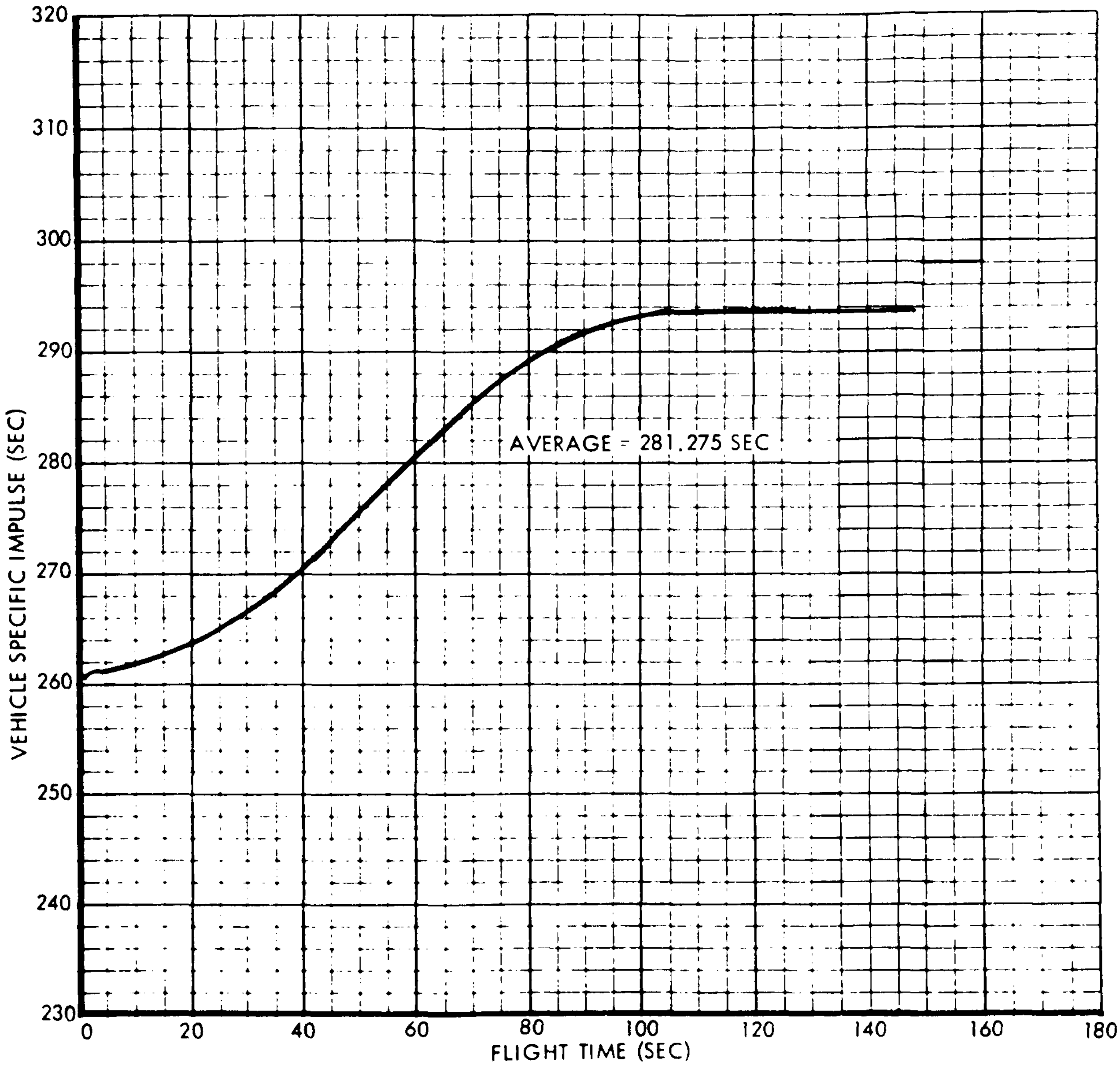

Figure 2. Vehicle Specific Impulse versus Flight Time

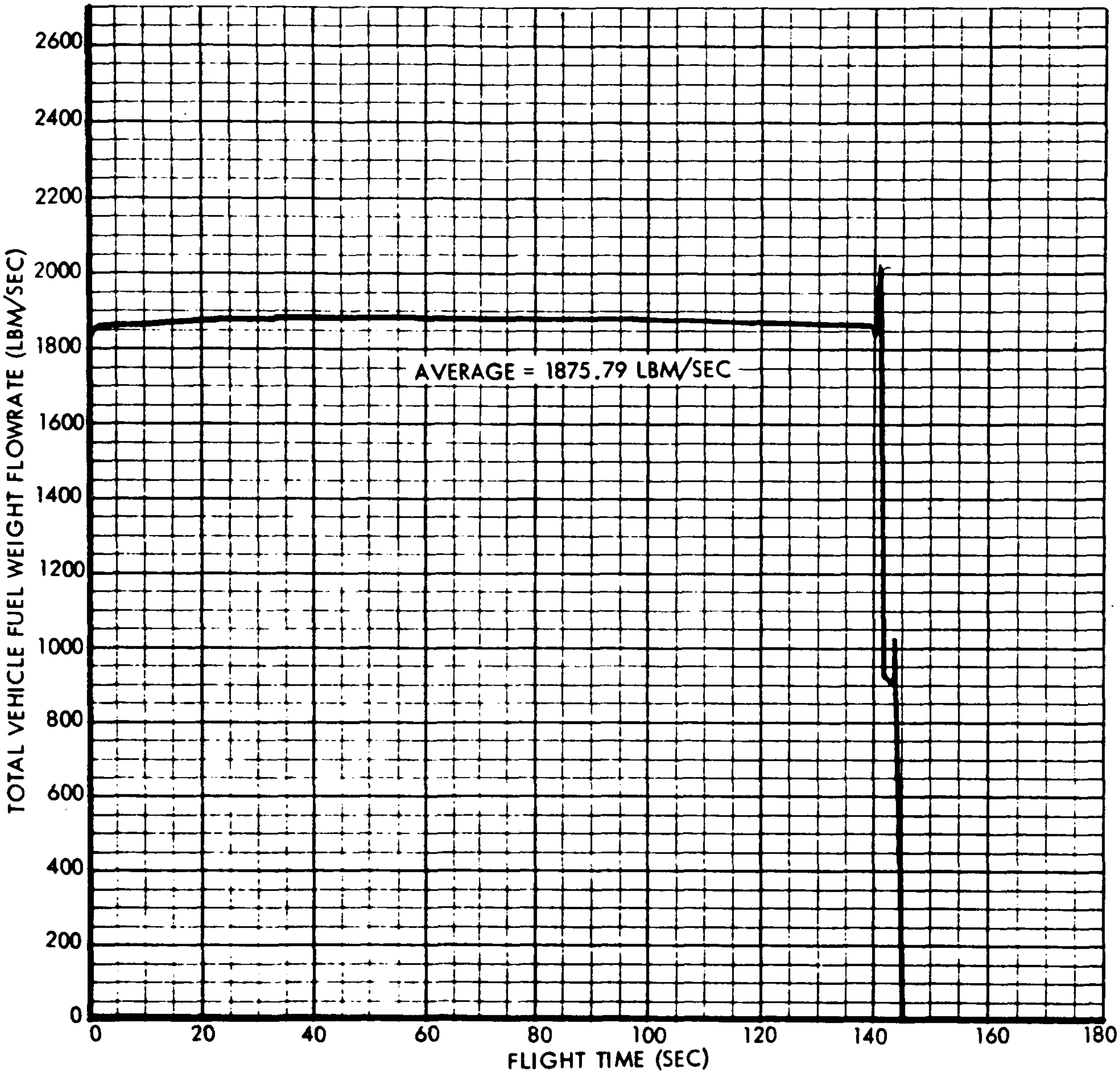

Figure 3. Total Vehicle Fuel Flowrate versus Flight Time

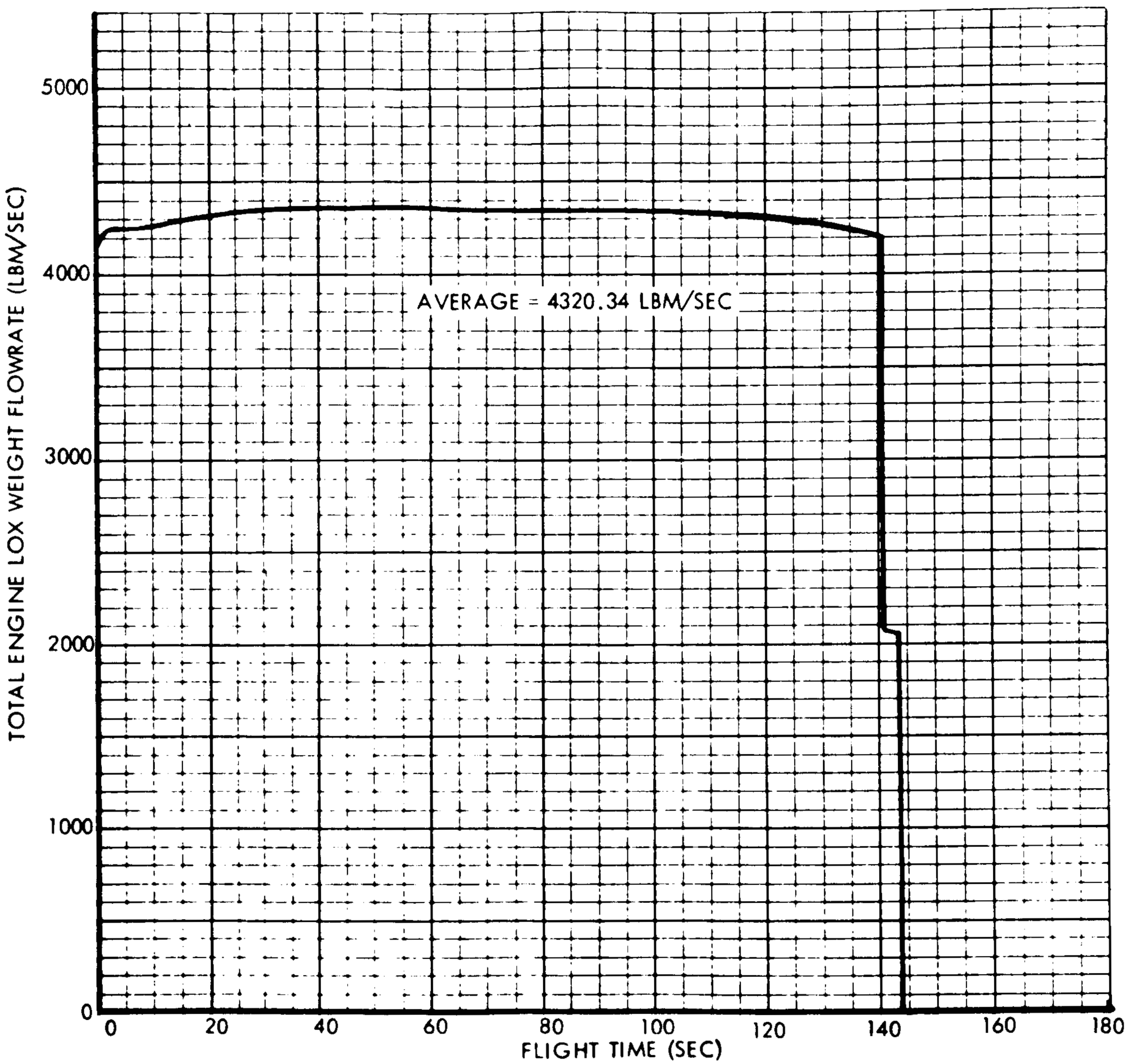

Figure 4. Total Engine LOX Flowrate versus Flight Time

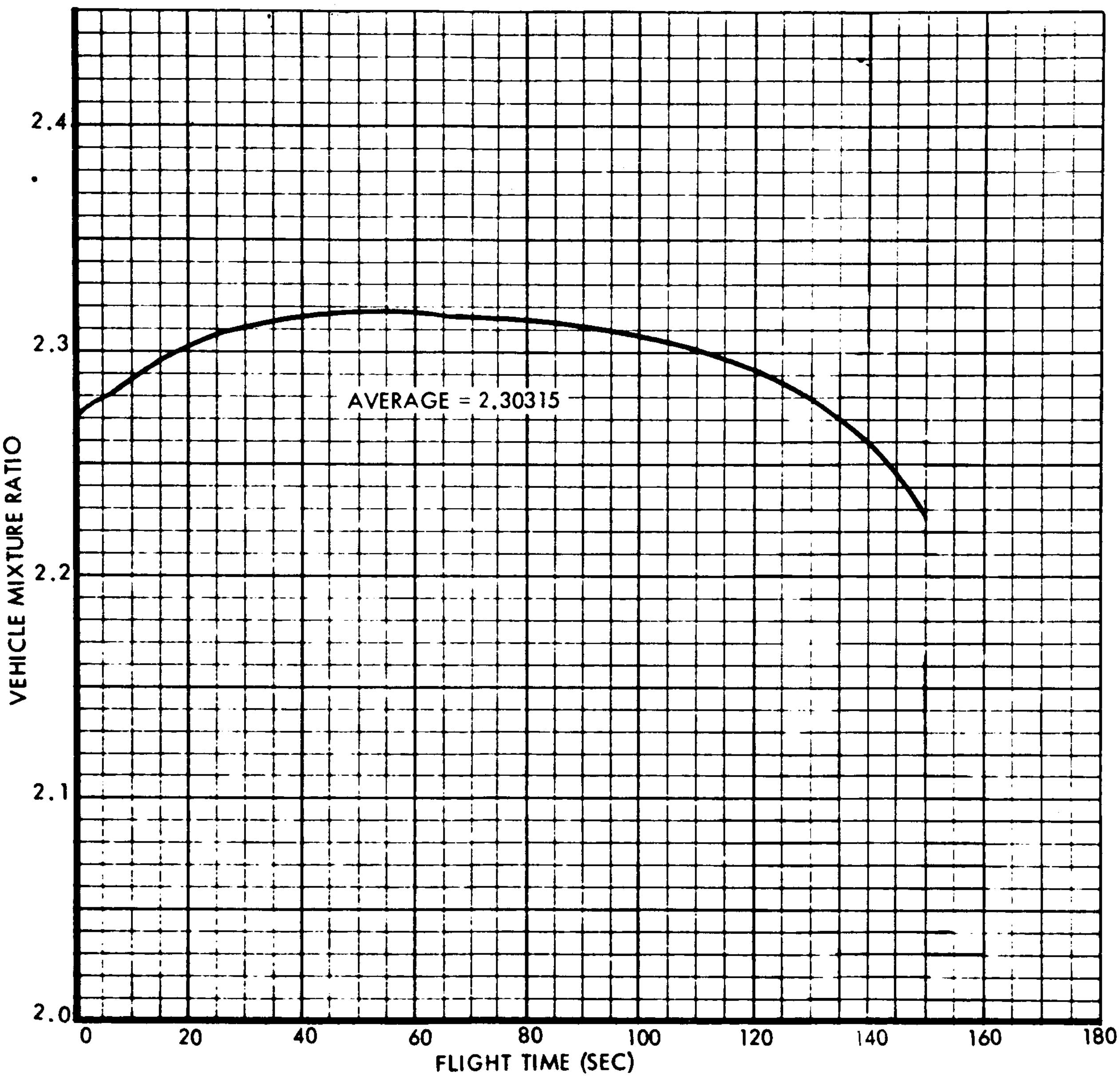

Figure 5. Vehicle Mixture Ratio versus Flight Time

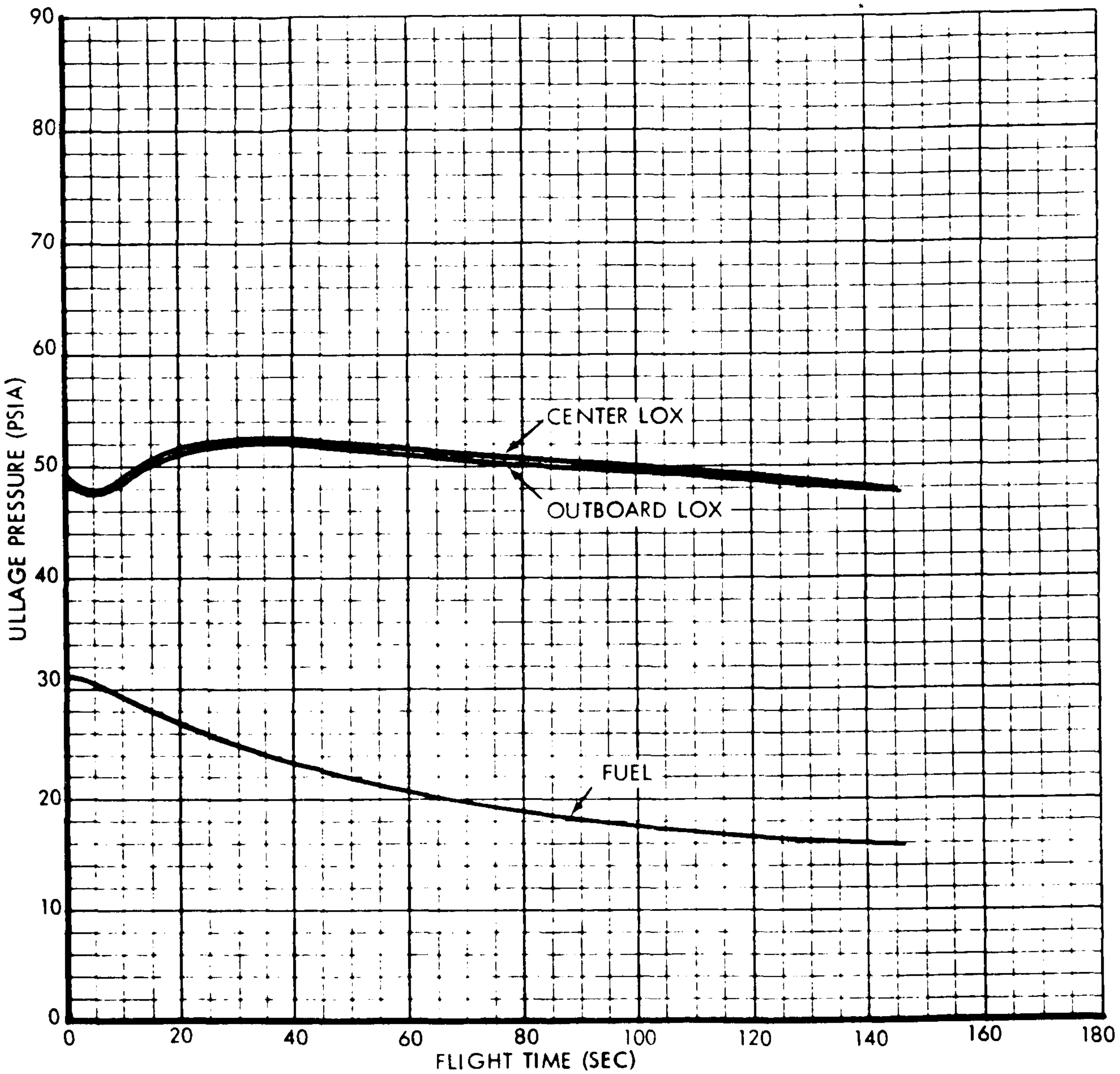

Figure 6. LOX and Fuel Tank Ullage Pressure versus Flight Time

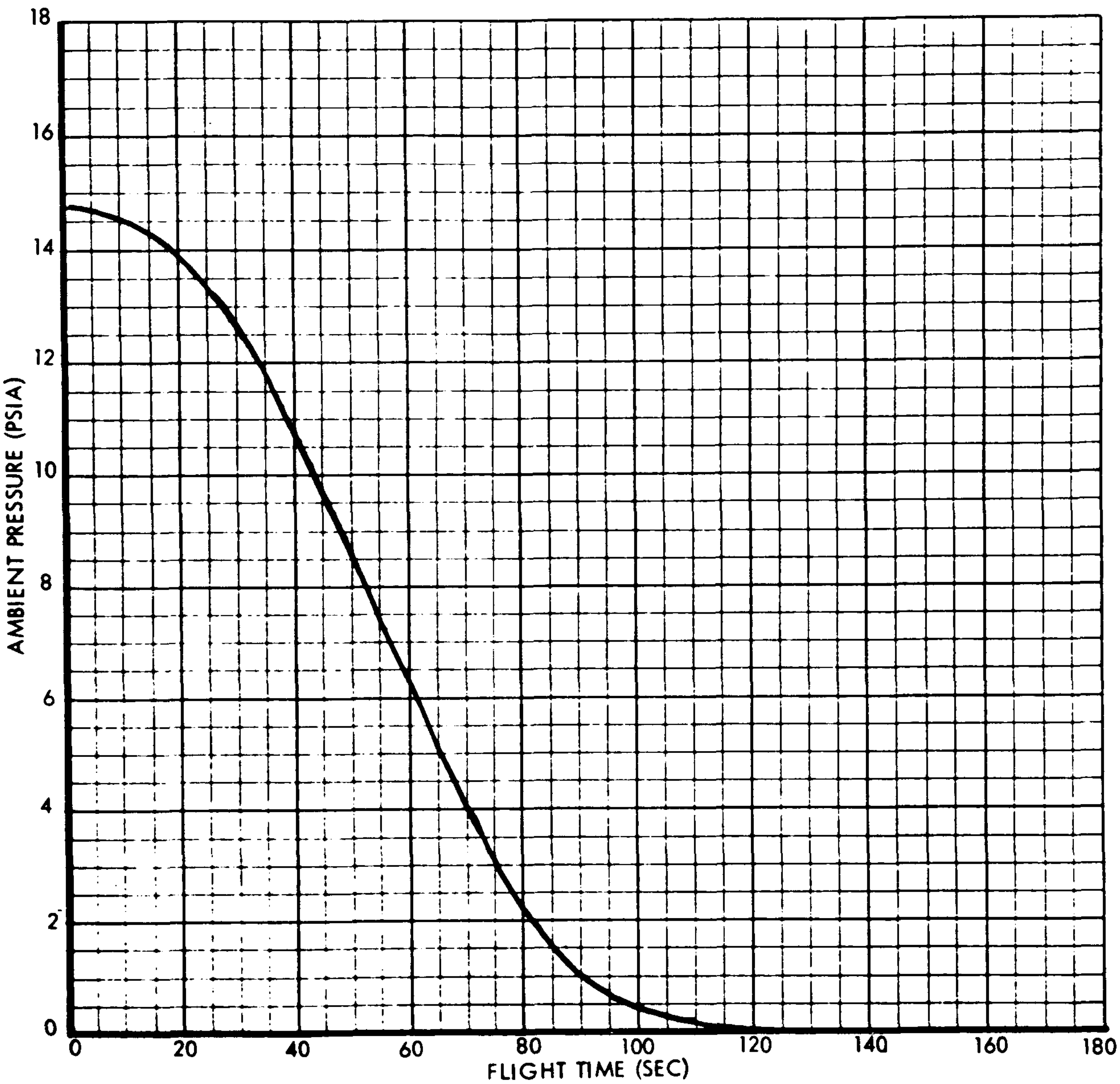

Figure 7. Ambient Pressure versus Flight Time

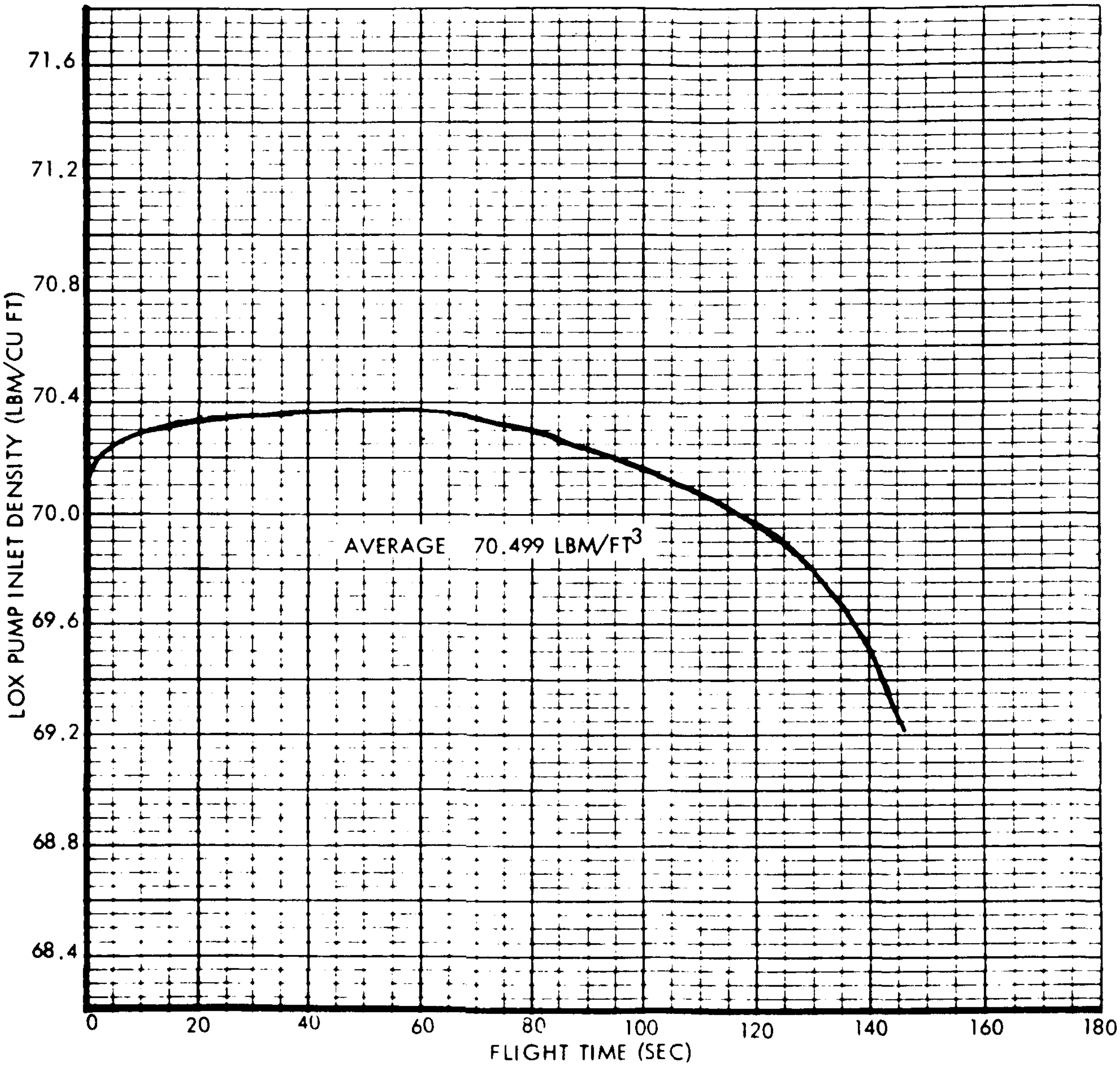

Figure 8. Engine LOX Pump Inlet Specific Weight versus Flight Time

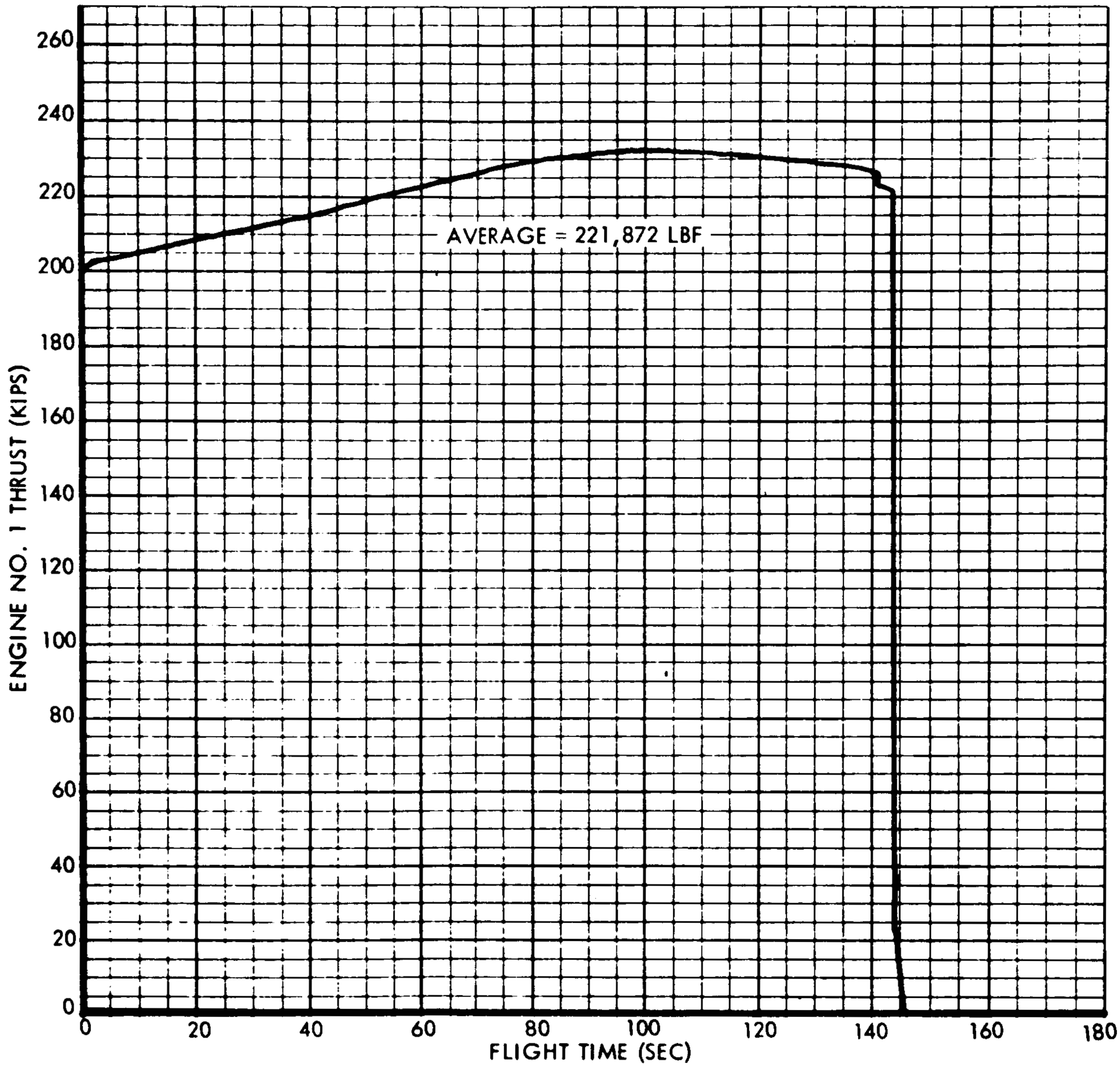

Figure 9. Typical Engine Thrust versus Flight Time

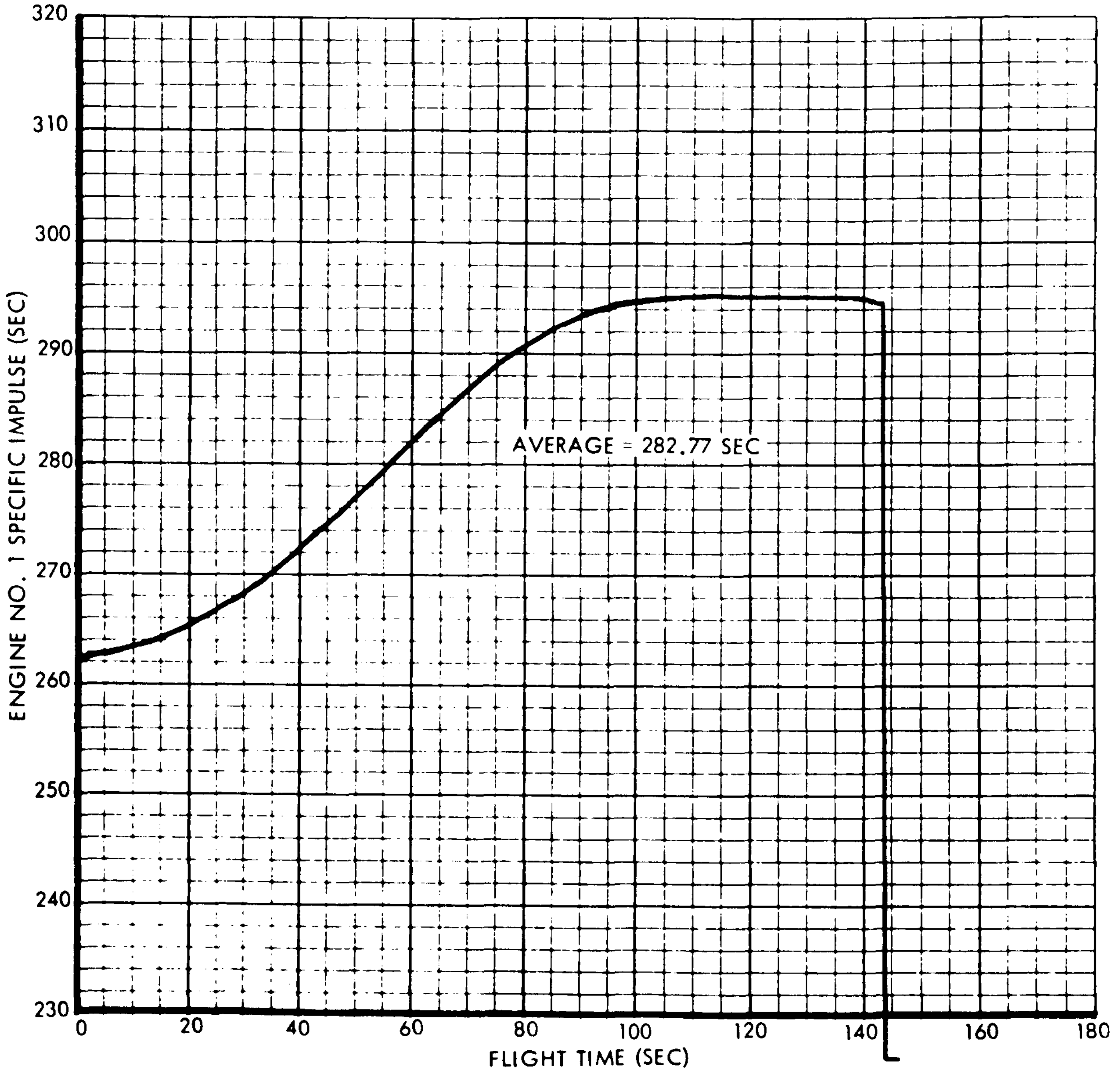

Figure 10. Typical Engine Specific Impulse versus Flight Time

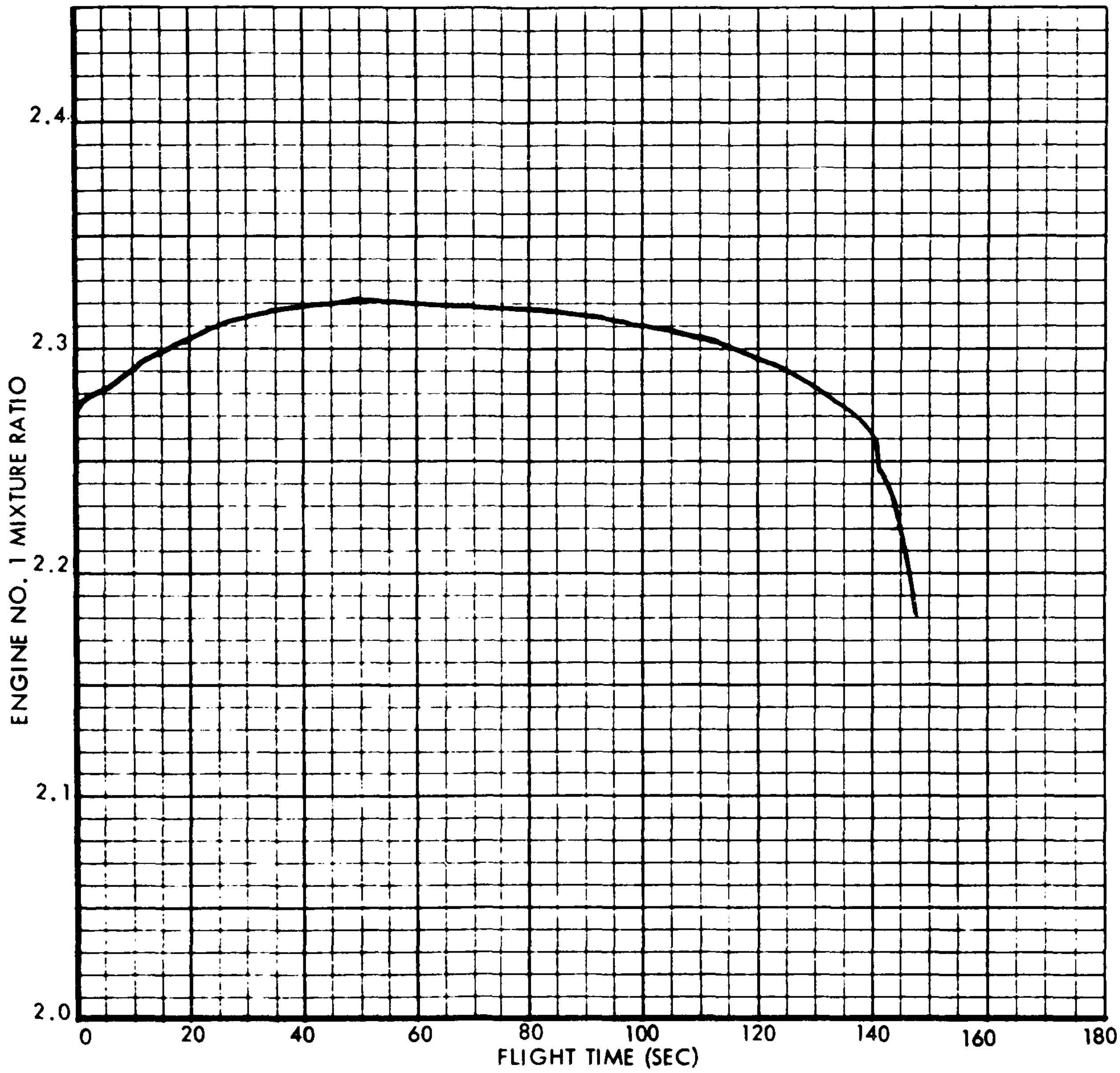

Figure 11. Typical Engine Mixture Ratio versus Flight Time

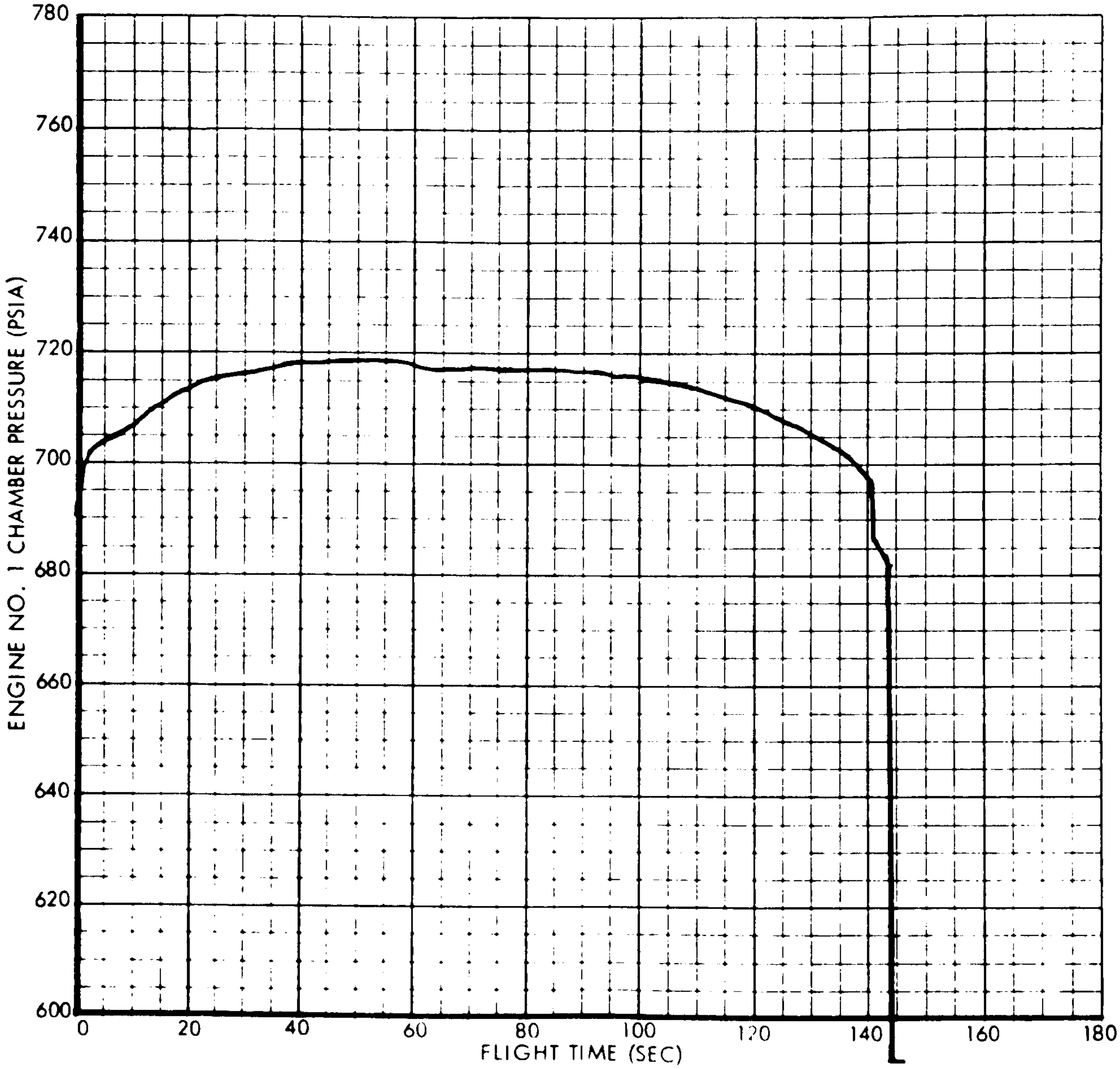

Figure 12. Typical Engine Chamber Pressure versus Flight Time

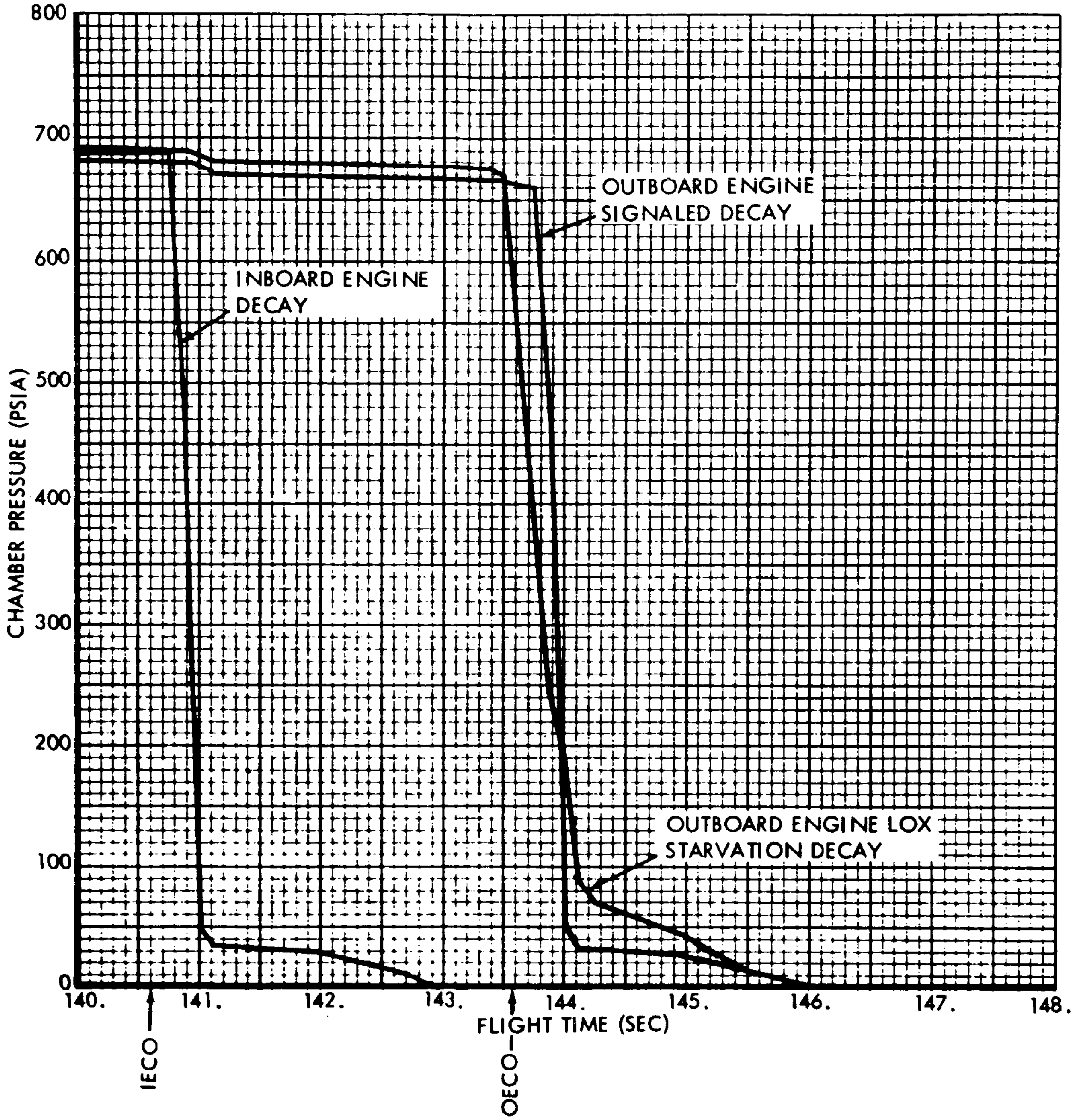

Figure 13. Typical Inboard and Outboard Engine Chamber Pressure Decay Relative to IECO

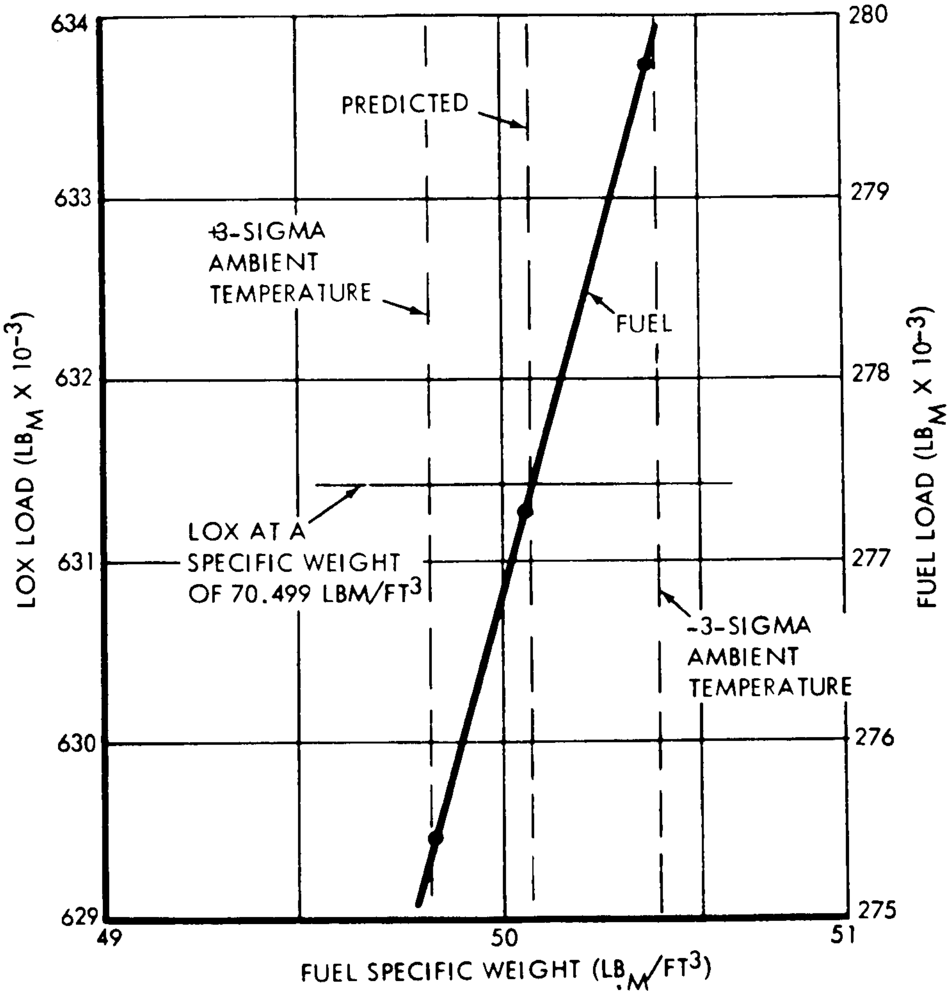

Figure 14. Propellant Load versus Fuel Specific Weight

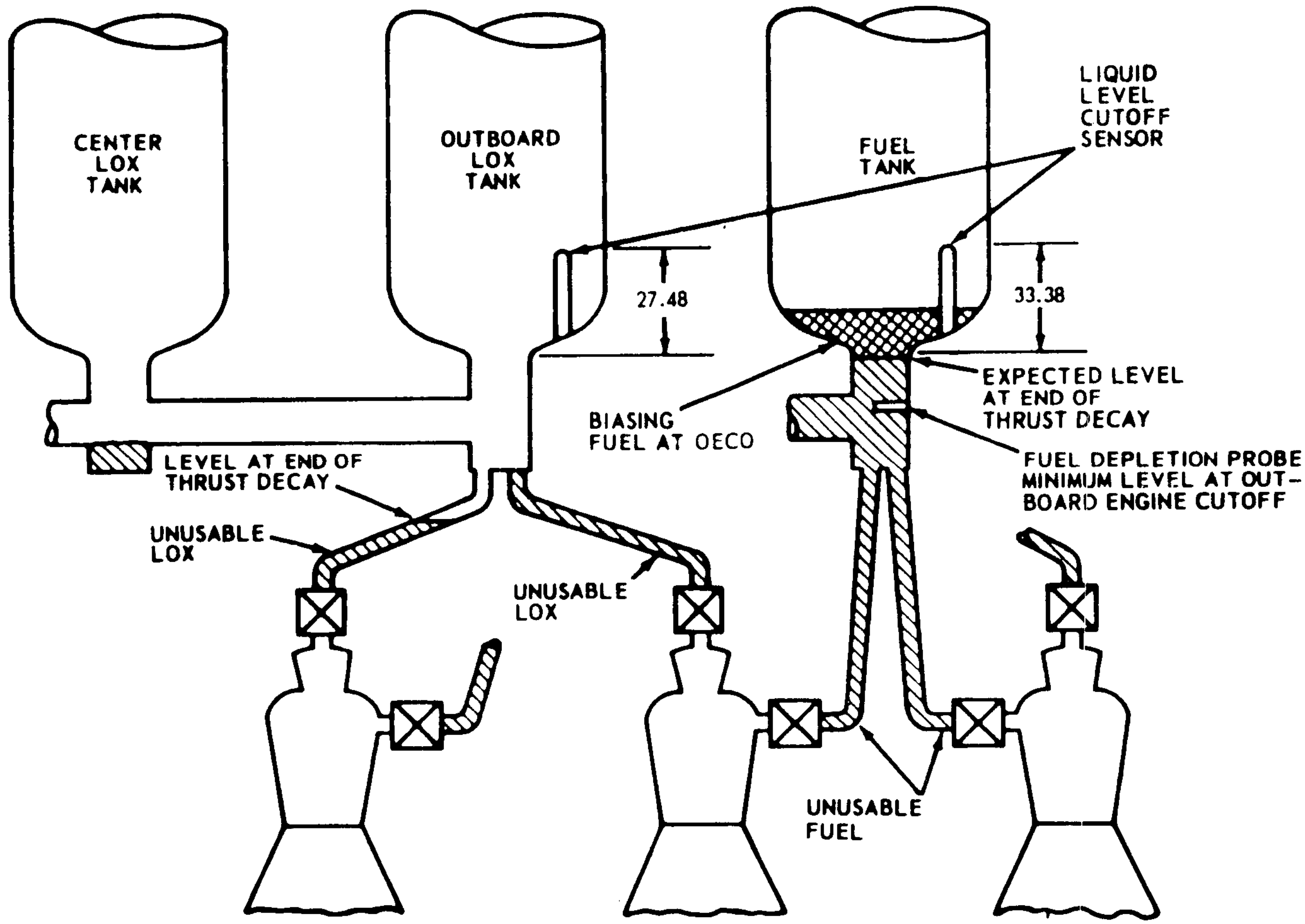

Figure 15. Propellant Depletion Requirements for S-IB-5 Stage

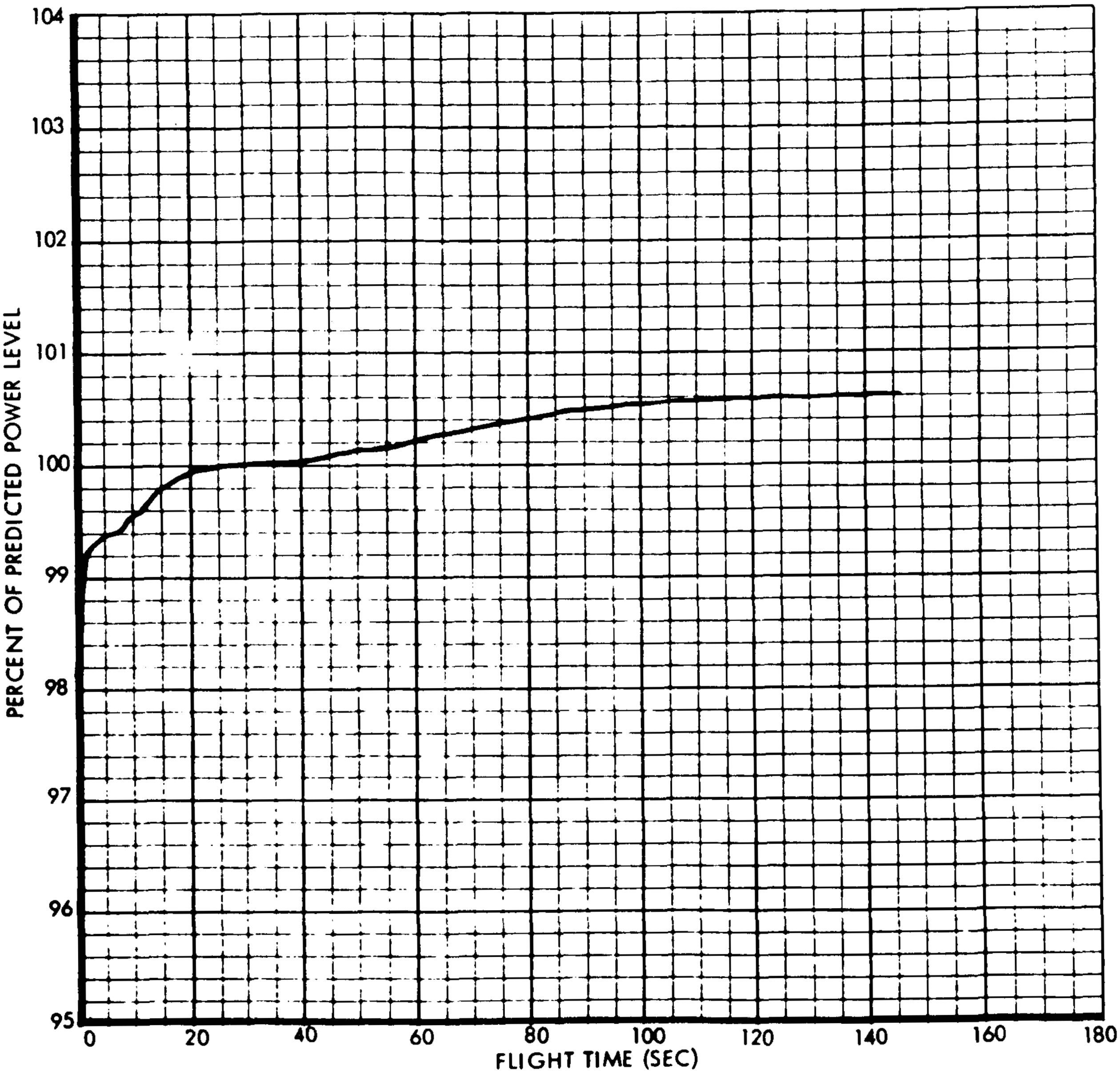

Figure 16. Predicted Power Level Shift versus Flight Time

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