COMPARISON STUDY OF FLUORINE/HYDRAZINE ENGINE CONCEPTS

Contract 7-100, PO 953943

Final Report
Report No. 2094-FR-1
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ABSTRACT

The Comparison Study of Fluorine/Hydrazine Engine Concepts examined the weight and performance of 600 lbF thrust liquid-liquid and bimodal engines as chamber pressure, mixture ratio, contraction ratio, combustion chamber and nozzle lengths, area ratio and operating duration were varied. This data is presented in more than 150 plots and tables. This parametric study was conducted following a design study which selected baseline engines for the liquid-liquid and bimodal systems. The design study indicated that ablative thrust chambers with carbon and graphite flame liners were best suited to the 1,000 to 2,000 second operating requirement. Non-pyrolyzing thrust chambers were found to be excessively heavy even at the lower duration.

The study results show the bimodal engine to have a lower weight, shorter length, and slightly higher performance over the entire range of operating conditions. If engine performance is maximized a 2,000 second duration bimodal engine has a weight advantage of twelve pounds. If engine lengths and weights are equal the bimodal engine's performance is ten seconds higher than that of the liquid-liquid engine. The operating flexibility of the bimodal engine offers substantial advantages with regard to system design. The liquid-liquid engine has a greater development history especially if other halogen oxidizer and amine fuel combinations are considered.

Advanced engine designs were also considered. It was determined that the weight of a bimodal engine with a ducted thrust chamber using hydrazine decomposition products for a combination of regenerative, inter-regen and film cooling would be nearly independent of operating duration. At baseline design conditions (P_c = 120 psia, area ratio = 60) this engine weighs twenty pounds which is sixteen pounds less than an engine having an ablative thrust chamber.

The length of the combustion chamber of the liquid-liquid engine can be reduced by the incorporation of a splash-plate element transverse-platelet injector to obtain improved fuel atomization and vaporization. The use of

ABSTRACT (cont.)

this injector would result in the performance and weight of the liquid-liquid engine being virtually the same as that of the baseline bimodal engine.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

FIGURE LIST

FIGURE LIST (cont.)

FIGURE LIST (cont.)

9

I. INTRODUCTION

The Comparison Study of Fluorine-Hydrazine Engine Concepts described herein was initiated with a conceptual design study of 600 lbF thrust bimodal and liquid-liquid engines.

The bimodal engine utilizes a Shell 405 catalyst monopropellant hydrazine reactor in the fuel circuit to decompose the fuel prior to its injection through the bipropellant injector. The designation bimodal is in reference to the capability of the engine to operate in the monopropellant mode using fuel only or in the bipropellant mode using the LF_2/N_2H_4 propellant combination. The liquid-liquid engine can operate only in the bipropellant mode. Its fuel and oxidizer are both injected as liquids.

The conceptual designs which resulted from the initial study were utilized to parametrically determine the effect of engine package envelope, chamber pressure and mixture ratio on engine performance (I_{sp}), materials of construction and mass. This parametric evaluation is presented as a series of plots and tabulations which show the interaction of engine length, nozzle area ratio, chamber pressure, mixture ratio, operating duration and weight.

The concept designs and parametric study are based on the use of near state-of-the-art components. It is assumed that injector development will be conducted to allow optimization of injector performance and injector-to-chamber compatibility. The basic designs of the catalytic reactor, injectors, thrust chamber and divergent nozzle extension are based on units which have been successfully fire tested with LF_2/N_2H_4 propellants.

The results of the comparison study indicate that the bimodal engine is always lower in weight and/or higher performing than the liquid-liquid engine. This results from the fact that the vaporized decomposed fuel permits the use of a substantially shorter combustion chamber. This, in turn, reduces the quantity of film or barrier cooling required and the attendant

I. Introduction (cont.)

performance losses. The following tabulation provides a point comparison of the two engine concepts. These are illustrated in Figures 1 and 2.

	Bimodal	Liquid-Liquid
Thrust	600 lbF	600 lbF
Chamber Pressure	120 psia	120 psia
Engine Envelope		
Length	27.4	32.4
Diameter	15.1 in.	15.1 in.
Inj-throat Length (L')	6.0 in.	12.0 in.
Contraction Ratio	2.50	2.25
Injector Energy Release Efficiency	99.0%	99.0%
% Fuel Film Cooling	5.0%	13.4%
Gas-side Wall Temperature	4000°F	4000°F
Nozzle Length	18.4 in.	18.4 in.
Nozzle Area Ratio	60	60
Exit dia	14.6 in.	14.6 in.
Specific Impulse	382.3 sec	379.8 sec
Mixture Ratio	1.7	1.7
Duration Capability	2,000 sec	2,000 sec
Engine Weight	35.9 lb	48.0 lb

Limited studies of advanced engine designs were accomplished with the intent of reducing engine weight and/or increasing engine performance. It was found that although the bimodal engine's performance is at a practical limit a substantial weight improvement could be achieved through the use of an advanced thrust chamber design.

The liquid-liquid engine suffers primarily from its longer length combustion chamber which has the effect of increasing weight and reducing performance due to the larger barrier fuel flow required to maintain the selected

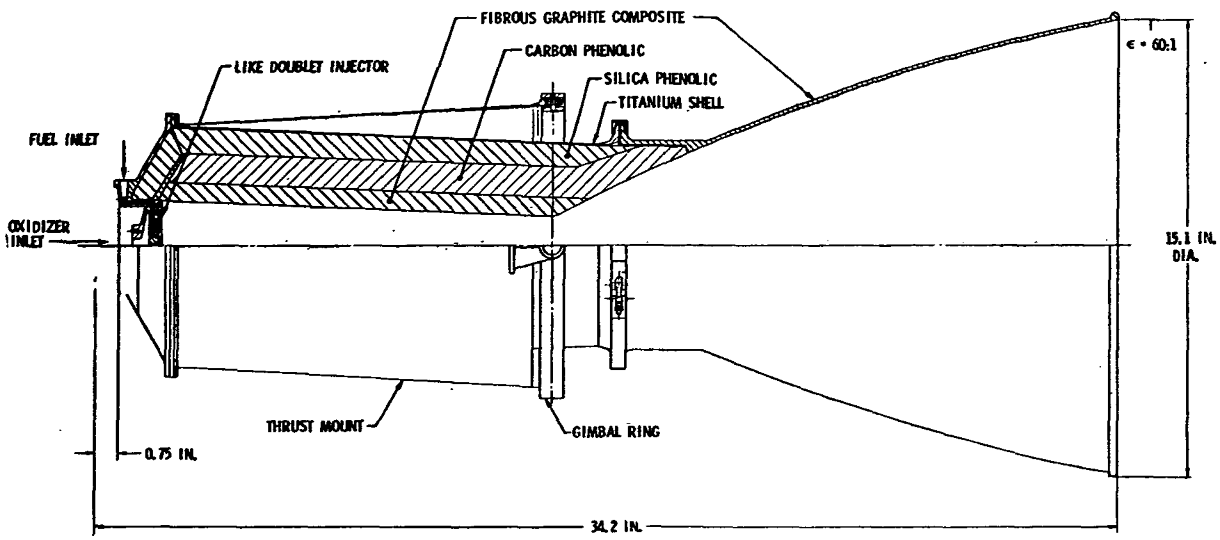


Figure 1. Liquid-Liquid Engine, Baseline Design

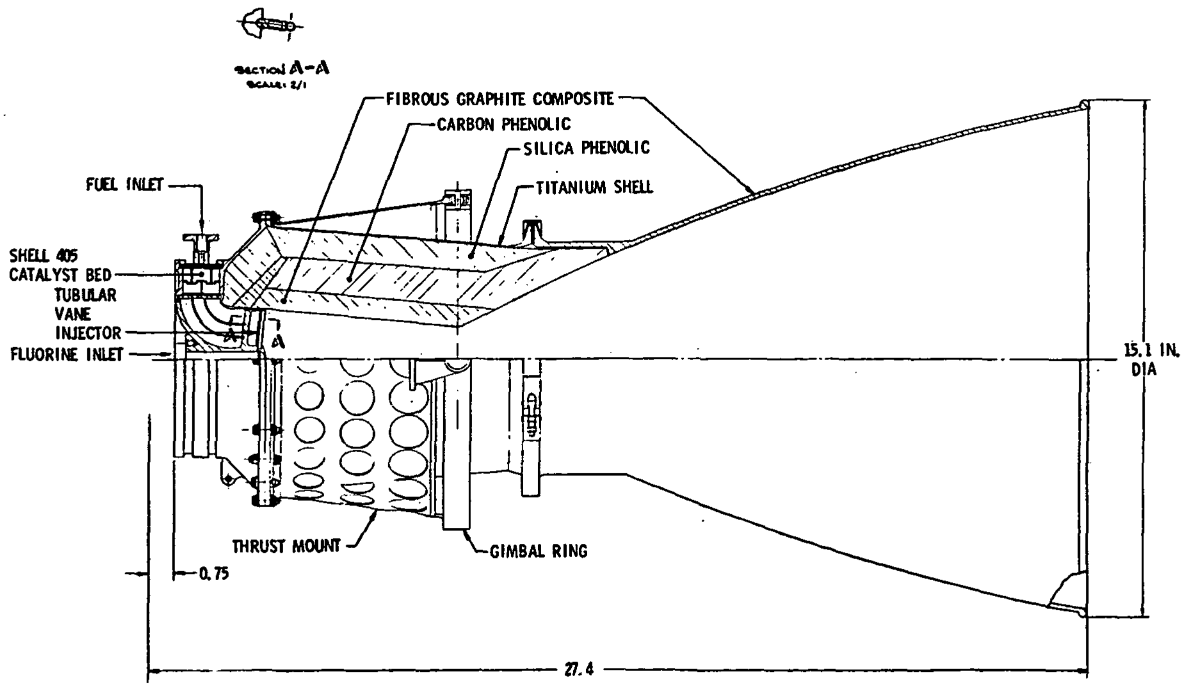


Figure 2. Bimodal Engine, Baseline Design

I, Introduction (cont.)

throat station gas wall temperature. Advanced injector design concepts which accelerate the atomization and vaporization of the fuel were examined. It was found that the use of an injector which mechanically atomized the fuel would allow the chamber length (L') to be reduced by 50% resulting in the liquid-liquid engine being weight competitive with the standard bimodal engine. The advanced thrust chamber design considered for the bimodal engine is not feasible for the liquid-liquid engine because it requires the availability of gaseous decomposed fuel for duct and barrier cooling.

II. CONCLUSIONS

The comparison study of the two engine concepts has produced quantitative performance and weight data as well as more qualitative systems evaluation data (Section VIII). Review of this information results in the following conclusions.

> The bimodal engine always has a higher performance than the liquid-liquid engine. Depending upon operating conditions, and envelope constraints, this performance advantage (I_{sp}) can range from 1.0 to 10.0 sec.
>
> The bimodal engine always has a lower weight than the liquid-liquid engine. The weight advantage can range from 10 to 15 pounds depending upon chamber pressure and area ratio (based on L' = 12 liquid-liquid engine).

This weight and I_{sp} disparity is due primarily to a single parameter, injector to throat distance (L'). In order to achieve the same injector energy release efficiency as the bimode engine, the liquid-liquid unit requires an added six inches of chamber length which results in a need for added film coolant. The length produces more chamber weight; the film coolant causes a performance decrement.

> The liquid-liquid engine to have a slightly greater development history in terms of time, quantity of tests and hardware fabricated.

A misconception of the development status of the liquid-liquid engine development occurs if other halogen oxidizers (e.g., FLOX, ClF_3 and ClF_5) and amine fuels (e.g., MMH, MHF-3[1] and BA 1014[2] are included in the tabulation of liquid-liquid development experience. These data are relevant to the

(1) MHF-3; 86% MMH + 14% N_2H_4

(2) BA 1014; 67% N_2H_4 + 9% H_2O + 24% MMH

II, Conclusions (cont.)

thrust chamber design and its durability; they are less significant in terms of fluorine-hydrazine injector operation. In fact, in some instances, blended hydrazine fuels were introduced on a program due to an inability to obtain satisfactory operation with neat hydrazine.

The systems evaluation results show the bimodal engine to offer significant operating advantages. These include the following:

Step throttling. Bipropellant operation results in 600 lbF thrust; monopropellant mode operation is at a thrust of 150 lbF.

Continuous throttling in the monopropellant mode. This requires the use of a throttling valve in the fuel circuit.

Throttled starts; monopropellant operation always immediately preceeds the bipropellant firing.

Elimination of a need for a positive displacement oxidizer expulsion system. The monopropellant mode firing can be used to settle the oxidizer tank.

Improved propellant utilization; residual fuel can be utilized in the monopropellant mode.

Partial system redundancy. The monopropellant system can be operational in spite of an oxidizer malfunction.

15

III. RECOMMENDATIONS

The comparison study whose results are presented in this report is based upon certain assumptions which, although considered conservative, have not been experimentally verified. These are as follows:

Both bimodal and liquid-liquid injectors can produce an ERE of 99.0%.

Thrust chamber wall temperatures can be maintained at 4000°F or less.

Chemical reactions at the gas-side of the thrust chamber wall will not result in unacceptable wall regression.

In addition, various aspects of the engine design have not been analyzed in depth. Significant analytic deficiencies include the following:

An absence of an engine thermal model and soak out analysis which identifies heat flow to the fuel injector, propellant valves, and spacecraft lines and structure.

An absence of a data which will identify the temperature of the fuel circuits during soak out. This is critical if an engine restart closely follows a long duration bipropellant firing.

These deficiencies do not adversely affect the object of the study reported herein which was to compare the performance and weight of bimodal and liquid-liquid engines. Absolute performance values and weights could be influenced by added analytic and experimental data. The weight and performance differences of the bimodal and liquid-liquid engines would be only slightly affected.

16

III, Recommendations (cont.)

The design studies conducted on this program have identified new approaches to the design of the bimodal and liquid-liquid engines which offer a potential for reduced engine weight and reduced engine length and weight, respectively. These are considered feasible however due to the absence of experimental data they have not been incorporated into the baseline designs.

The following activities are recommended for future programs. These are categorized for each engine type and are listed in a suggested priority order.

A. SYSTEMS AND MISSIONS ANALYSES

1. Conduct mission analyses to define the interrelation of engine weight and performance.

> This trade-off is essential to the selection of the engine configuration (bimode versus liquid-liquid) as well as a selection of the optimum length liquid-liquid engine.

2. Conduct mission studies to determine whether the operating flexibility (throttling and step thrust) of the bimodal engine provides an advantage in terms of system weight or reliability.

> The bimodal engine's operating flexibility must be quantified to permit a more realistic comparison of liquid-liquid and bimode engine concepts.

3. Conduct a comparison study of candidate oxidizer valves evaluating the use of squib-actuated valves as well as conventional motor and solenoid driven valves as they effect mission flexibility and the use of bimodal and liquid-liquid engines.

III, A, Systems and Missions Analyses (cont.)

The use of the bimodal engine avoids the need for multi-firing operation of the engine as low ΔV maneuvers can be conducted in the monopropellant mode. The use of the bimodal engine with multiple squib-actuated oxidizer valves may be more weight and cost effective than a conventional valve used with the liquid-liquid engine.

B. BIMODAL ENGINE

1. Design, fabricate, flow test and fire test a next generation hub-fed tubular-vane injector.

This is necessary to the achievement of the 99% ERE assumed in this study as well as development of improved injector-chamber compatibility.

2. Design, fabricate and demonstrate a long duration capable flightweight thrust chamber.

The existence of an adequate injector (see above) is a prelude to this task. The 2,000 sec duration thrust chamber is nonexistent. The industry's best fluorine experience is 420 sec continuous duration and 600 sec accumulated duration.

3. Complete engine-spacecraft interface designs which can be thermally modeled to forecast the soakout temperatures of the various components.

This thermal data is needed prior to the finalization of the flight engine design to insure correct placement of valves and lines.

III, B, Bimodal Engine (cont.)

4. Conduct performance, heat transfer, stress and weight analysis of a duct cooled bimodal thrust chamber.

Duct cooling provides a technique which may preclude heat flow to the injector end of the engine while increasing the effectiveness of the hydrazine decomposition products used to film cool the throat. The result is that the heavy weight silica and graphite phenolic materials can be eliminated for a substantial engine weight reduction. Figure 3 shows a duct-cooled bimodal engine. Performance and weight analyses show that this design offers a weight reduction of more than 16 pounds when compared to the conventional point design bimodal engine. Further data is presented in Appendix C.

C. LIQUID-LIQUID ENGINE

1. Conduct detailed analyses of a transverse platelet injector designed for liquid fluorine-liquid hydrazine propellants; design, fabricate and fire test the selected design.

The use of an advanced injector design is essential if the liquid-liquid engine is to be competitive with the bimodal unit in performance and/or weight. The transverse platelet injector concept (see Figure 4) could provide liquid-liquid engine performance comparable to that of the bimodal within the same length chamber. This could result in an engine weight reduction of 15 pounds. Further data is presented in Appendix D.

2. Design, fabricate, flow test and fire test a next generation like-doublet injector.

19

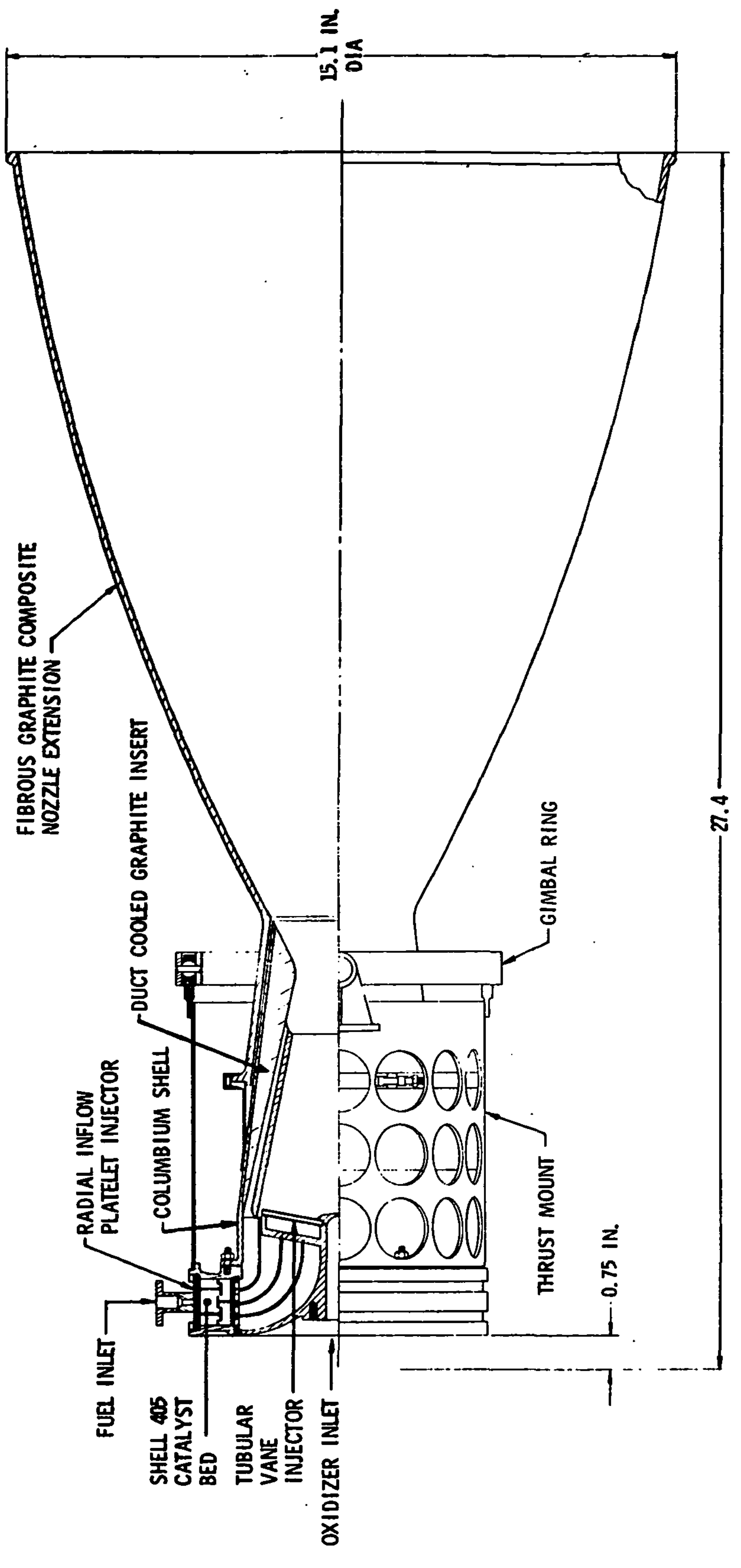
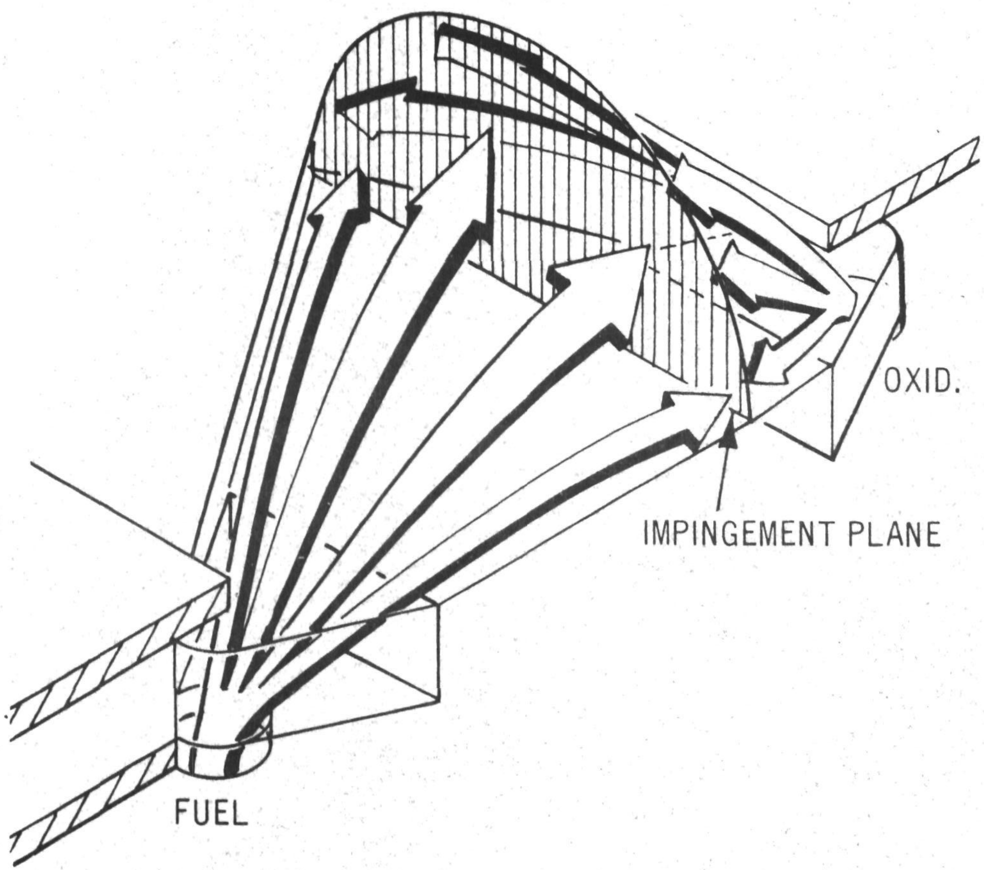


Figure 3. Light-Weight Duct-Cooled Bimodal Engine



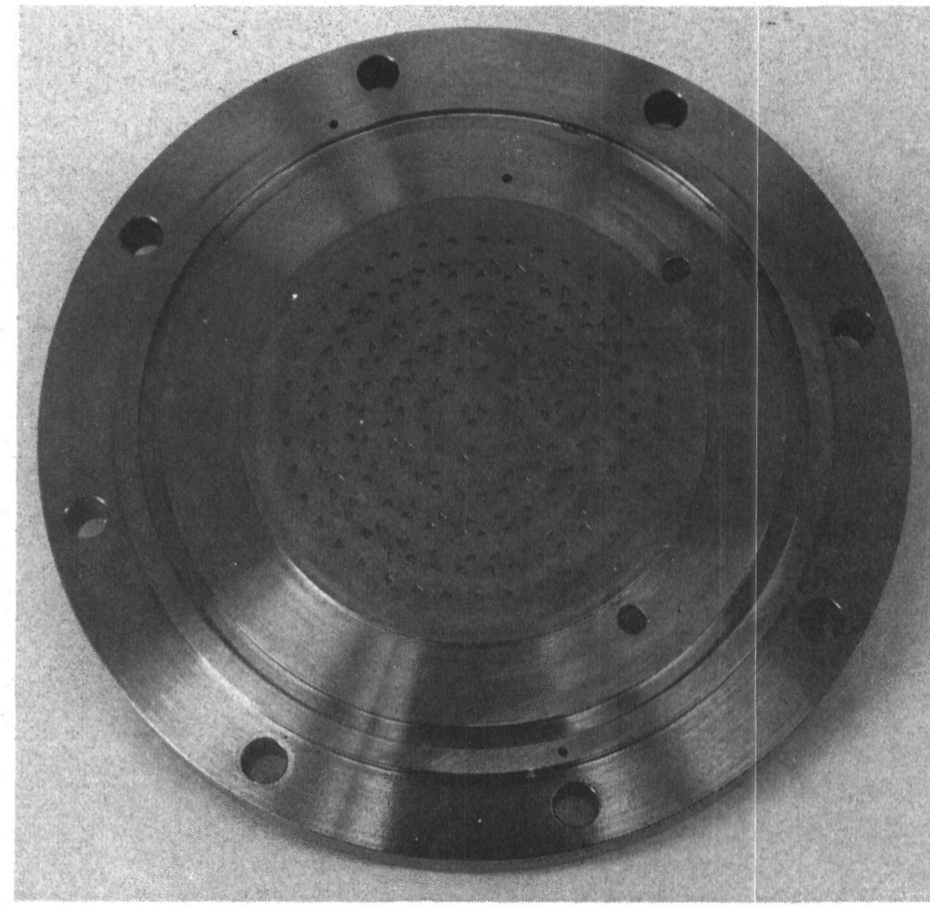


Figure 4. Transverse Platelet Injector

III, C, Liquid-Liquid Engine (cont.)

This is necessary to the achievement of the 99% ERE and injector-chamber compatibility assumed in this study.

3. Design, fabricate and demonstrate a long duration capable flightweight thrust chamber.

The existence of an adequate injector (see above) is a prelude to this task. The 2,000 second duration chamber is nonexistent. The industry's best fluorine experience is 420 seconds continuous duration and 600 seconds accumulated duration.

4. Complete engine-spacecraft interface designs which can be thermally modeled to forecast the soakout temperatures of the various components.

This thermal data is needed prior to the finalization of the flight engine design to insure correct placement of valves and lines.

IV. ENGINE DESIGN DEFINITION

The development of the performance and weight data for the liquid-liquid and bimodal engines required that engine designs be selected to provide baselines for the parametric studies. These designs evolved from a review of the engine operating requirements as defined by NASA-JPL and the examination of the state-of-the-art for liquid-liquid and bimodal injectors, passively cooled thrust chambers and radiation cooled divergent nozzle extensions. The selected baseline designs are illustrated in Figures 1 and 2 which show liquid-liquid and bimodal engines, respectively. The engines shown in both figures meet the following point design requirements:

Thrust	- 600 lbF
Chamber pressure	- 120 psia
Nozzle area ratio	- 60
Duration capability	- 2,000 sec

Further engine operating characteristics are presented in the tabulation of Section I.

A. OPERATING REQUIREMENTS

The contract-defined study limits are presented in the following tabulation:

Parameter	Range
Thrust	600 lb
Propellants	LF_2/N_2H_4
Inlet Pressure	1.75 x P_c
Mixture Ratio, MR	1.4 to 1.8
Chamber Pressure, P_c	80 to 200 psia
Contraction Ratio Ac/At	1.5 to 5.0
Nozzle Area Ratio, Ae/At	40 to 80

23

IV, A, Operating Requirements (cont.)

Parameter	Range
Injector-Throat Distance, L'	6 to 15 in.
Engine Length	24 to 36 in.
Operating Duration	1,000 to 2,000 sec

The operating duration consists of a single continuous firing preceded by several five second firings and followed by several more short duration firings. In the case of the bimodal engine, the short pulses would be accomplished in the monopropellant mode of operation.

B. DESIGN SELECTION

1. Engine Configuration

The engine designs which are shown in Figures 1 and 2 present state-of-the-art configurations for liquid-liquid and bimodal engines respectively. The major differences between the two concepts are as follows:

The bimodal engine utilizes a gas-liquid injector. The fuel passes through an integral catalytic reactor so that it is injected as a gaseous mixture of N_2H_4 decomposition products, i.e., NH_3, N_2 and H_2.

The liquid-liquid engine uses a conventional drilled orifice like-doublet injector.

The bimodal engine has a shorter combustion chamber because "stay time" is not required to either atomize or vaporize the fuel.

The two engine concepts are alike in the selection of the chamber materials, the use of ablatives for passive cooling, and the design of the divergent nozzle extension.

IV, B, Design Selection (cont.)

In both instances, the injector is fabricated from nickel to insure compatibility with the oxidizer at elevated temperatures. The gas side liner of the chamber may be fabricated from bulk graphite or carbon and graphite composite materials. Aerojet's AG-Carb and Hitco's Pyrocarb are typical composite materials.

The materials which back the fibrous graphite liner serve two functions; liner support and thermal insulation of the chamber's external member. These materials are carbon reinforced phenolic and silica reinforced phenolic. The use of phenolics is essential to the achievement of the extended operating duration without undue weight. The heat of pyrolysis of the phenolics results in a chamber whose weight is about 40% less than that of a non-pyrolyzing configuration.

The structural member which contains the carbon and silica phenolic inserts and provides a mechanical attachment to the injector and gimbal mounting structure is made from 6Al-4V titanium alloy. This is surrounded by a low-density non-structural insulation which insures that the outside surface of the thrust chamber assembly does not exceed 800°F. The titanium case can soak to 2000°F temperatures without adverse effect. The maximum case temperature during operation is 1000°F.

The divergent nozzle extension is clamped to the aft flange of the chamber's titanium case. It is made from a fibrous graphite composite as is the chamber liner but is intended to be cooled by radiation. The cylindrical offset at the nozzle extension's flange isolates the forward end of the nozzle from the combustion products. Additionally, it minimizes the nozzle-to-flange thermal gradient to avoid excessive thermally induced bending loads at the nozzle flange.

The gimbal system consists of a titanium gimbal ring which has a rectangular cross-section. It is secured to the conical thrust mount by

IV, B, Design Selection (cont.)

two bolts through self-aligning spherical bearings retained in the gimbal ring with threaded retainers. One of the bearings is fixed at the inner race by the bolt passing through it. The other bearing is free to slide allowing for thermal expansion of the conical thrust mount. The gimbal ring would be similarly secured to the vehicle by means of bearing housings which bolt to the vehicle structure.

2. Injector

a. Bimodal Injector

The design of the monopropellant reactor and secondary injector is based on the lightweight radial in-flow Shell 405 catalyst reactor and the hub fed tubular vane injector tested by ALRC on Contract NAS 2-6483. This injector configuration is one of four tested on the referenced contract. Figure 5 summarizes the development experience gained with each of the four.

The platelet vane injector and hub fed tubular vane injectors had nearly equivalent performances. The feature of the tubular vane design is that of the four injectors evaluated it alone offered high performance coupled with thermal isolation of the oxidizer. Control of heat flow to the oxidizer is necessary to the maintenance of design pressure drop and adequate control of the operating mixture ratio.

The performance data obtained with this injector indicated a demonstrated energy release efficiency (ERE) of 97.8%. The hot fire and cold flow test data disclose that this design has a mixture ratio distribution (MRD) loss due to a concentration of the fuel flow toward its axis. This resulted in a higher than desired peripheral MR which was adverse with regard to both chamber compatibility and performance.

- RADIAL INFLOW
  - ALRC TESTED 6 TESTS, 52 SEC N_2O_4/N_2H_4
    4 TESTS, 40 SEC LF_2/N_2H_4
  - PERFORMANCE: 73% I_{sp}
  - COMPATIBILITY: POOR
- RADIAL OUTFLOW (SPUD) ALRC TESTED 10 TESTS, 80 SEC N_2O_4/N_2H_4
  4 TESTS, 45 SEC LF_2/N_2H_4
  - PERFORMANCE: 48% I_{sp}
  - COMPATIBILITY: VERY GOOD
- PLATELET VANE - ALRC TESTED 13 TESTS, 65 SEC N_2O_4/N_2H_4
  15 TESTS, 173 SEC LF_2/N_2H_4
  - PERFORMANCE: 88% I_{sp} - 2 PHASE OX FLOW
  - COMPATIBILITY: GOOD
  - STABILITY - SUCCESSFULLY BOMB TESTED 3 TIMES
- HUB-FED TUBULAR VANE - ALRC TESTED 4 TESTS, 58 SEC LF_2/N_2H_4
  - PERFORMANCE: 89% I_{sp}
  - COMPATIBILITY: CHAMBER POOR, THROAT GOOD
  - JPL TESTED 9 TESTS, 40 SEC LF_2/N_2H_4
  - PERFORMANCE: 94% I_{sp}

Figure 5. Bimodal Injector Development History

IV, B, Design Selection (cont.)

The performance study conducted on this program is based on the assumption that added injector development will allow the MRD loss to be reduced and an ERE of 99.0% attained. This ERE value is typical of the Aerojet Apollo and OME injectors.

b. Liquid-Liquid

Halogen oxidizer injectors evaluated by JPL, ALRC and AFRPL were reviewed using the data sources tabulated below.

Contractor	Configuration	Data Source
JPL	Like Doublet	} SSPM Thrust Chamber Assembly Report
JPL	Unlike Doublet	
ALRC	Triplets	Contract F04611-67-C-0003 Reports
ALRC	Triplets	ALRC IR&D Report 94-F
ALRC	Triplets and Doublet	ALRC IR&D Report 71-F
AFRPL	Like Doublet	Contract F04611-68-C-0034 Reports

Detailed information obtained from these sources are summarized in Figure 6. These data indicate that although there is a substantial data base with halogen oxidizers, the use of neat hydrazine fuel has been limited. Review of the subject information resulted in the conclusion that the like-doublet element offered good performance (ERE = 97.5%) good chamber compatibility and dynamic stability at the 600 lbF thrust level. Although the unlike-doublet and triplet elements appeared to have slightly higher performance in some instances they were rejected on the basis of less experience with F_2/N_2H_4 and evidence of poorer chamber compatibility and less favorable stability characteristics.

28

INJECTOR ORIGIN	ELEMENT TYPE	ELEMENT QUANTITY	THRUST	P_C	L'	ORIFICE DIA. FUEL	ORIFICE DIA. OXID	PROPELLANT FUEL	PROPELLANT OXID	TEST QUANTITY	ACCUM. DUR., SEC	PERF. % ISP THEO	REMARKS
JPL	L-O-L	24	600	100	9.5	.017-.020	.022	MMH	FLOX	39	600	82 (ALT)	STABLE, GOOD COMPATIBILITY.
JPL	L-O-L	24	600	100	9.5	.017-.020	.022	N_2H_4	LF_2	20	60	87 (ALT)	STABLE, GOOD COMPATIBILITY
JPL	UD	22	600	100	9.5	.036-.021	.060-.021	MMH	FLOX	10	500	84 (ALT)	STABLE, POOR COMPATIBILITY
ALRC	F-O-F	68	7,000	100	16.5	.043	.083	BA1014(1)	LF_2	19	869	90.5	STABLE, FAIR COMPATIBILITY
ALRC	F-O-F	344	7,000	100	16.5	.020	.035	BA1014	LF_2	10	166	93.5	STABLE, GOOD COMPATIBILITY
ALRC	F-O-F	69	3,000	400	9.0	.036	.052	BA1014	CLF_3	8	26	93.5	UNSTABLE, 3 OF 8.
ALRC	F-O-F	69	2,800	300	9.0	.028	.046	MHF-3(2)	CLF_3	4	4	-	STABLE
ALRC	F-O-F	69	2,800	300	9.0	.028	.046	N_2H_4	CLF_5	2	7	91	UNSTABLE
ALRC	UD	113	2,800	300	9.0	.026	.037	N_2H_4	CLF_5	1	5	89.6	UNSTABLE
ALRC	F-O-F	32	2,800	300	9.0	.034	.059	N_2H_4	CLF_5	2	2	94.2	UNSTABLE
ALRC	F-O-F	32	2,800	300	9.0	.034	.059	MMH	CLF_5	12	40	79-87	STABLE, GOOD COMPATIBILITY
AFRPL	L-O-L	144	5,000	300	13.0	.016	.020	MMH	CLF_3	9	594	91-94	STABLE, GOOD COMPATIBILITY
AFRPL	L-O-L	144	5,000	300	13.0	.016	.020	BA1014	CLF_3	5	323	92	STABLE, GOOD COMPATIBILITY
AFRPL	L-O-L	144	5,000	500	13.0	.016	.020	M-20(3)	CLF_3	2	7	95	STABLE, GOOD COMPATIBILITY

(1) BA1014 - 67% N_2H_4 + 9% H_2O + 24% MMH.

(2) MHF-3 - 86% MMH + 14% N_2H_4.

(3) M-20 - 80% N_2H_4 + 20% MMH

L-O-L like on like element

UD unlike doublet

F-O-F fuel-ox-fuel triplet

Figure 6. Liquid-Liquid Injector Operating Experience

IV, B, Design Selection (cont.)

As a result, the JPL like-doublet injector was selected as the baseline design for the liquid-liquid engine. The features of this injector are as follows:

It has been proven durable on repeated long duration firings. Aerojet's experience with similar nickel injectors includes accumulated firing durations in excess of 1,000 sec.

The manifold system can be fabricated by using either drilled passages or a diffusion bonded assembly. There is no weight difference between the two fabrication concepts.

The performance of the like-doublet element is good although it is fuel vaporization limited. The minimum fuel orifice dia used in this study was 0.013 inches.

The JPL like-doublet injector has been bomb tested to prove its dynamic stability. The study showed that if the incorporation of an acoustic damper were necessary it would not affect engine weight.

Thrust chamber compatibility has been good with both JPL and AFRPL like-doublet injectors.

Injector face cooling and propellant thermal management have not been a problem on any of the designs examined.

Section V, Performance Analysis, of this report presents detailed performance data obtained from JPL like-doublet injector testing. It was assumed that the demonstrated injector efficiency could be improved with limited development. Hence the performance studies are based

IV, B, Design Selection (cont.)

on an injector efficiency of 99% which would be typical of any selected element at the conclusion of a development activity.

3. Thrust Chamber

The bimodal and liquid-liquid engines have the same requirements in terms of thrust, chamber pressure and operating duration. It is anticipated that with suitable development, both injector types will provide the desired thermal and chemical environment at the chamber wall. The result is that both engines can use the same chamber design. The major difference is that the liquid-liquid engine requires an increased chamber length to provide equivalent performance.

The thrust chamber design process consisted of three tasks. These were to (1) examine existing designs and test experience gained with passively cooled fluorine thrusters, (2) compile materials properties for all candidate materials of construction, and (3) conduct thermal analyses which would identify the effect of material selection on chamber weight.

a. Industry Experience

Review of published data and ALRC experience obtained with fluorine oxidizer/amine-fuel thrusters disclosed that thrust chamber designs can be separated into the three categories described below:

I All ablative. These use graphite phenolic and carbon phenolic flame liners which are sometimes backed by silica phenolic. External cases are either metal or glass wrapped.

II Ablative with flame liner. These are similar to above except that erosion resistance liners (i.e., bulk graphite and fibrous

31

reinforced graphite composites) are contained within the silica and graphite reinforced phenolic materials.

III Free standing. The flame liners are used to contain the combustion process without the benefit of external structure.

Figure 7 summarizes the development history of the three categories. The actual test experience acquired with each is presented in Figure 8. This data resulted in the conclusion that Category I designs are unsuitable to long duration operation while the free standing thrust chambers of Category III are insufficiently developed to be considered state-of-the-art. The occurrence of throat erosion with Category II and III designs shown in Figure 8 generally resulted from a lack of injector design maturity rather than chamber deficiencies.

This review resulted in two versions of the Category II configuration being examined for the fluorine hydrazine engine usage. One utilized precharred material throughout to preclude the generation of pyrolysis gasses and dimension changes attendant to the use of phenolic impregnated materials. The second version was very nearly the same except that carbon, graphite and silica reinforced phenolics backed the flame liner insert. This design benefits from the heat of pyrolysis of the phenolic to obtain a thinner wall than the all-heat sink non-pyrolyzing configuration.

b. Material Properties Compilation

Candidate materials and their mechanical, weight and thermal properties are summarized in Figures 9 and 10. A decision with regard to the exact composition of the flame liner was unnecessary since the candidate materials all had similar densities. This is also true with regard to the densities of silica and graphite reinforced phenolics. Variations in fiber

CATEGORY I	GRAPHITE PHENOLIC FLAME LINERS, SILICA PHENOLIC INSULATION, EXTERNAL STRUCTURAL MEMBER. LIMITED DURATION CAPABILITY FAILURE MODE - FLAME SURFACE REGRESSION
CATEGORY II	EROSION RESISTANCE FLAME SURFACES: BULK GRAPHITE, PG, PYROCARB AND AGcarb ARE CONTAINED WITHIN GRAPHITE-PHENOLIC & SILICA-PHENOLIC INSULATION SYSTEMS; EXTERNAL STRUCTURAL MEMBER DEMONSTRATED DURATIONS APPROACHING 1000 SEC FAILURE MODES - LOCAL STREAKING, CRACKING AND NON-RETENTION OF LINER; LIMIT CONDITION - SILICA INSULATION MELTS DESIGN DEFICIENCY - WALL THICKNESS INCREASE WITH DURATION
CATEGORY III	FLAME SURFACE & STRUCTURE ARE SYNONYMOUS FAILURE MODE - MECHANICAL FAILURE OF LINER DESIGN DEFICIENCY - NO REDUNDANCY OF STRUCTURE; - MATERIALS PROPERTIES ARE CRITICAL - DIFFICULT ATTACHMENT AT INJECTOR INTERFACE

Figure 7. Thrust Chamber Development Status

CONTRACT OR REPORT	PROPELLANTS	DESIGN CATEGORY	CHAMBER DIA.	DURATION	P_c, PSIA	FAILURE MODE
AFRPL TR-65-138	LF_2/N_2H_4 BLEND	(6 UNITS	D_c=8.0	270 (MAX)	100	GAS SIDE CHUNKING
AFRPL TR-66-77	LF_2/N_2H_4 BLEND	(8 UNITS)	D_c=2.25	40 (MAX)	150-200	THROAT EROSION
		(1 UNIT)	D_c=2.40	10	200	THROAT EROSION
AFRPL TR-66-322	LF_2/N_2H_4 BLEND	CATEGORY I	D_c=7.22	160	100	THROAT EROSION
		CATEGORY I	D_c=7.22	350	200	THROAT EROSION (70%)
		CATEGORY II	D_c=7.22	250	175	LINER FAILURE(1)
		CATEGORY III	D_c=7.22	250	100	NO DEGRADATION
AFRPL TR-69-2	LF_2/N_2H_4 BLEND	CATEGORY II	D_c=9.25	600	100	LOCAL STREAKING
JPL SSPM TCA	FLOX/MMH	CATEGORY II	D_c=3.0	420	100	NO DEGRADATION
		CATEGORY II	D_c=3.0	420	100	SEVERE STREAKING
AFRPL TR-70-24	CTF/MMH and CTF/N_2H_4 BLEND	CATEGORY II	D_c=6.0	400	300	NO DEGRADATION
		CATEGORY III	D_c=6.0	10	400	LINER FAILURE(2)

(1) ASCRIBED TO POOR CURE OF Carb-I-Tex MATERIAL
(2) PROPELLANT TRAPPED IN DELAMINATION DETONATED

Figure 8. Thrust Chamber Test Experience

FUNCTION	MATERIAL	TEMP LIMITS °F	K BTU/IN.-SEC-°F X 107	ρ LB/IN.^{3}	KXP
FLAME LINERS	AgCarb	5000	3500	0.052	182
	BULK GRAPHITES		5000	0.062	310
LINER SUPPORT AND INSULATION (CARBON FAMILY)	P.G.		130	0.079	10
	GRAPHITE PHENOLIC CHAR	4000	1600	0.046	73
	GRAPHITE PHENOLIC	1000	220	0.054	12
	CARBON PHENOLIC CHAR	4000	685	0.040	274
	CARBON PHENOLIC LAM	1000	550	0.052	29
	PYROFOAM FPA 20	4000	160	0.011	1.8
LINER SUPPORT AND INSULATION (SILICA FAMILY)	CHAR	3100	120	0.042	5
	PHENOLIC	1000	48	0.063	3
STRUCTURAL CASE	GLASS	400	-	0.06	-
	TITANIUM	1500	-	0.16	-
	STAINLESS STEEL	2000	-	0.3	-
	COLUMBIUM	2500	-	0.35	-
NON STRUCTURAL INSULATION	MIN K 2000	2000	8	0.012	0.093
	DYNA QUARTZ	2700	60	0.0036	0.215

Figure 9. Materials and Thermal Properties

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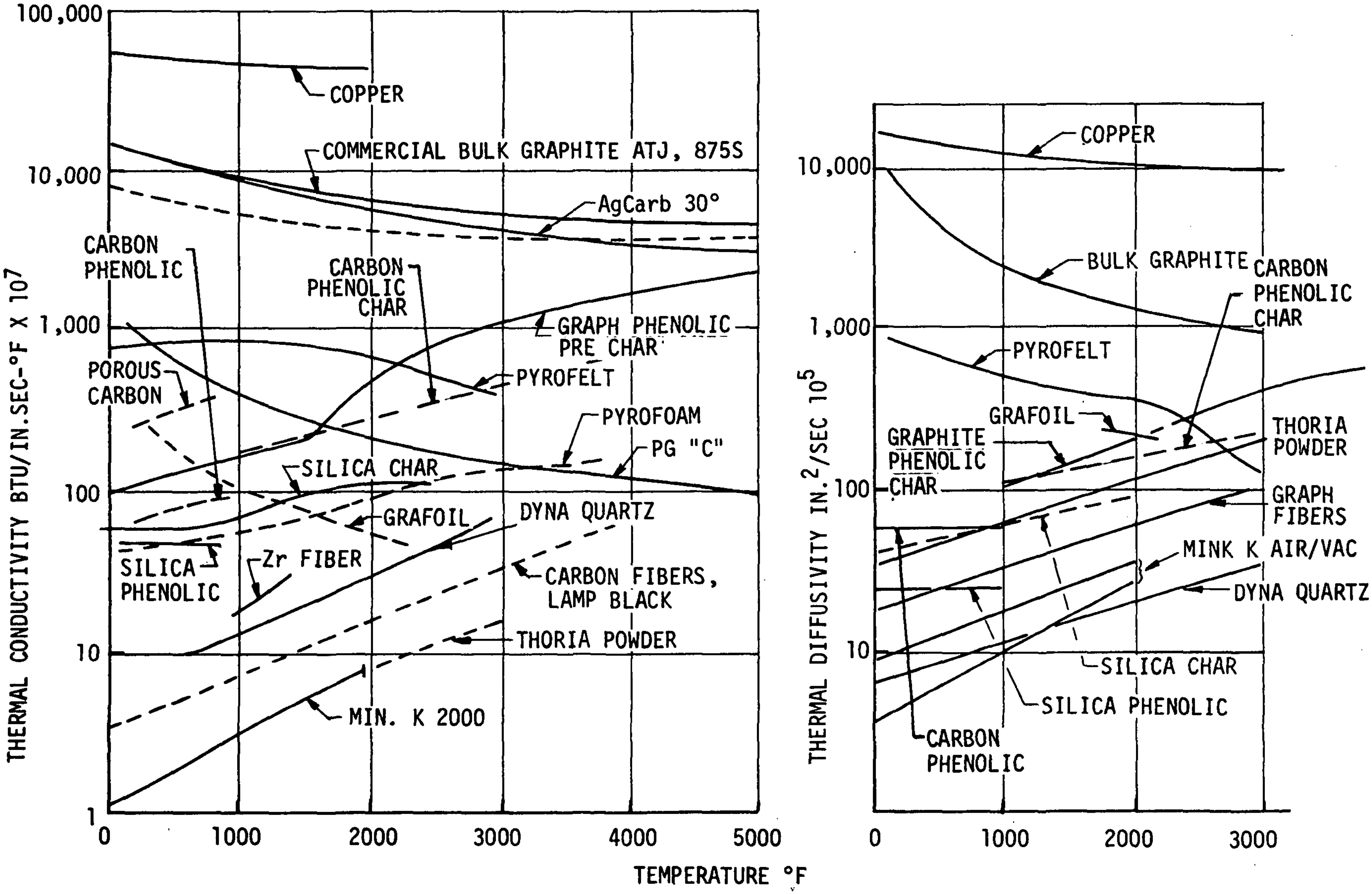


Figure 10. Conductivity and Diffusivity of Candidate Materials

orientation and resin content which may affect the performance of the materials have a small effect on engine weight. This resulted in the selection of classes of materials rather than singular formulations. The selection was based upon three criteria; prior experience, thermal properties and material density.

c. Thermal Design

The design of the thrust chamber was accomplished in two steps. The first was to evaluate the effect of the material selection and gas side wall temperature (recovery temperature) on the material thickness necessary to the maintenance of either 500°F or 2,000°F steady state temperatures at the chambers structural shell. External insulation which has minimal effect on thermal design would be used to maintain any selected skin temperature. Gas side wall temperatures of 3,000°F and 5,000°F were utilized. Engine operating duration was assumed to be 1,000 sec. This information was compiled in the bar chart which is shown in Figure 11.

It should be noted that all chamber designs utilized a 0.60-in. thick graphite flame liner. Figure 11 does not show external structure surrounding the outboard member as the chamber case is sufficiently thin that it has virtually no influence on the chamber's thermal design.

Designs (16) and (17) in Figure 11 fall into the Category III configuration (reference II,B,3,a) and hence were not seriously considered as design candidates. They are included as they represent minimum weight configurations. The designs which incorporated silica materials were configured so that the silica would not exceed 3,000°F which is about 200° below its meeting temperature.

The thickness data presented in Figure 11 was used to calculate the weight of the various thrust chamber designs. It was assumed

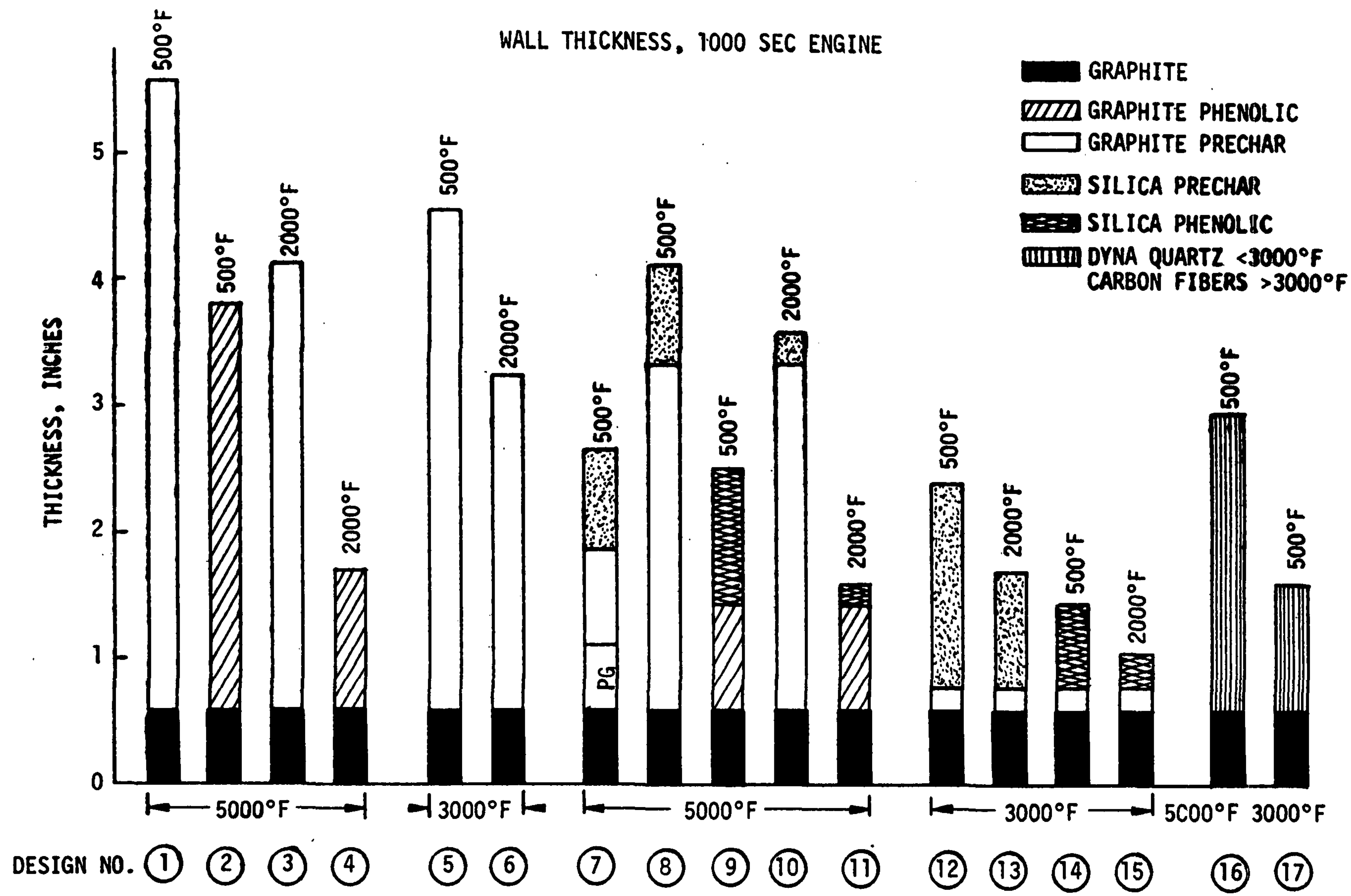


Figure 11. Effect of Materials and Gas and Back-Side Temperatures on Thrust Chamber Wall Thickness

that the thrust chamber's weight would be equivalent to a 12.0 inch long cylindrical unit with a constant 3.0 inch inside diameter. This resulted in thrust chamber weights ranging from less than ten pounds to 85 pounds. Figure 12 presents the calculated weights of the seventeen candidate engine designs. It is obvious that the lowest weight units (excluding Designs (16) and 17) utilize phenolic materials which pyrolyze (outgas), have high backside wall temperatures and operate with low gas side wall temperatures.

The comparison of Designs (2) and (4) with (9) and (11) respectively shows silica phenolic to be more effective than graphite phenolic in maintaining a low back wall temperature.

The weights of the more suitable candidate thrust chamber designs are summarized in Figure 13. The 5000°F recovery temperature was utilized on the basis that the 3000° gas side wall temperature may either be unattainable or impose an unacceptable performance penalty. As previously stated, Design (16) is not considered a viable candidate. Comparison of Designs (7) and (9) shows the use of a nearly 0.5 inch thick PG graphite sleeve to provide little thermal advantage. This design was rejected due to the increased complexity required in assembly as well as concern that PG graphite with a 6/1 diameter-to-thickness ratio was unattainable.

The second part of the thermal design task was to analyze the anticipated chamber design (Design (9)) as operating duration was varied from 800 to 2200 seconds. The accuracy of the SINDA heat transfer analysis used to model the final chamber design was first verified by analytically forecasting the temperatures of the gas side liner to carbon phenolic and carbon phenolic to silica phenolic interfaces of a JPL thrust chamber which had been fired for 420 sec duration using a like-doublet injector operating with FLOX/MMH propellants. The good agreement of the calculated and measured values is illustrated in Figure 14. The material properties used in this analyses are presented in Figure 15.

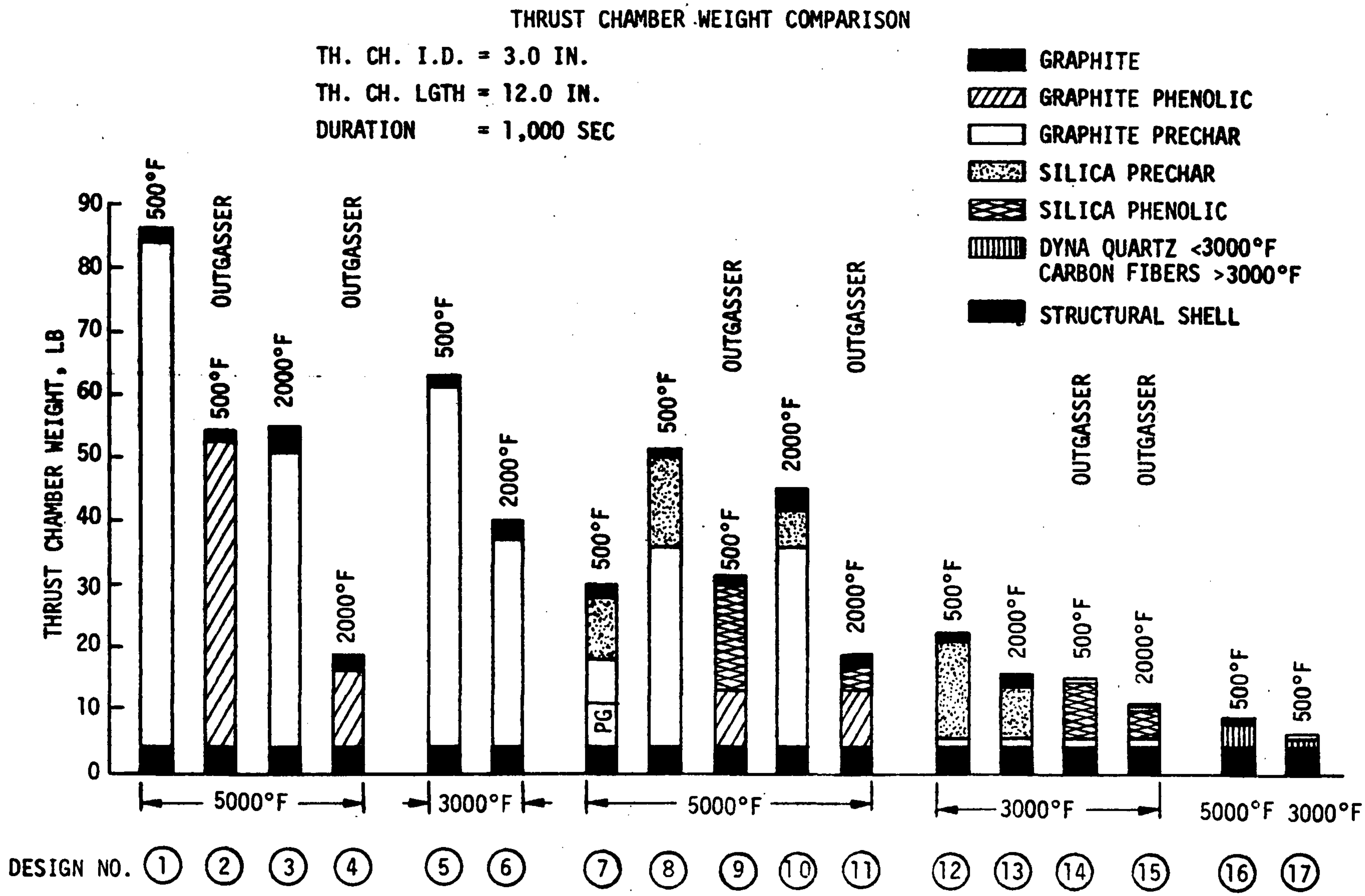


Figure 12. Effect of Materials and Wall Temperatures on Thrust Chamber Weights

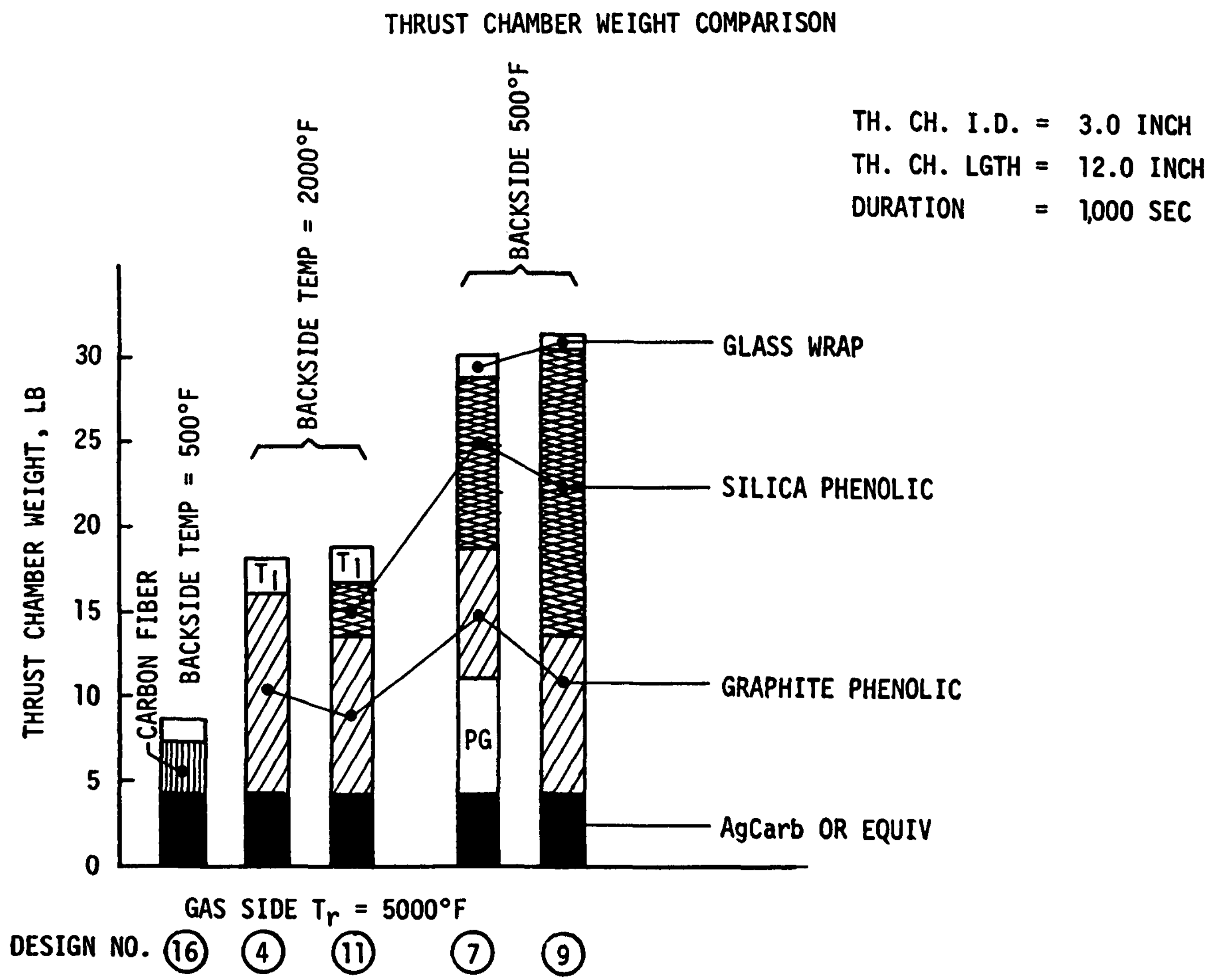


Figure 13. Candidate Thrust Chamber Material Combinations and Weights

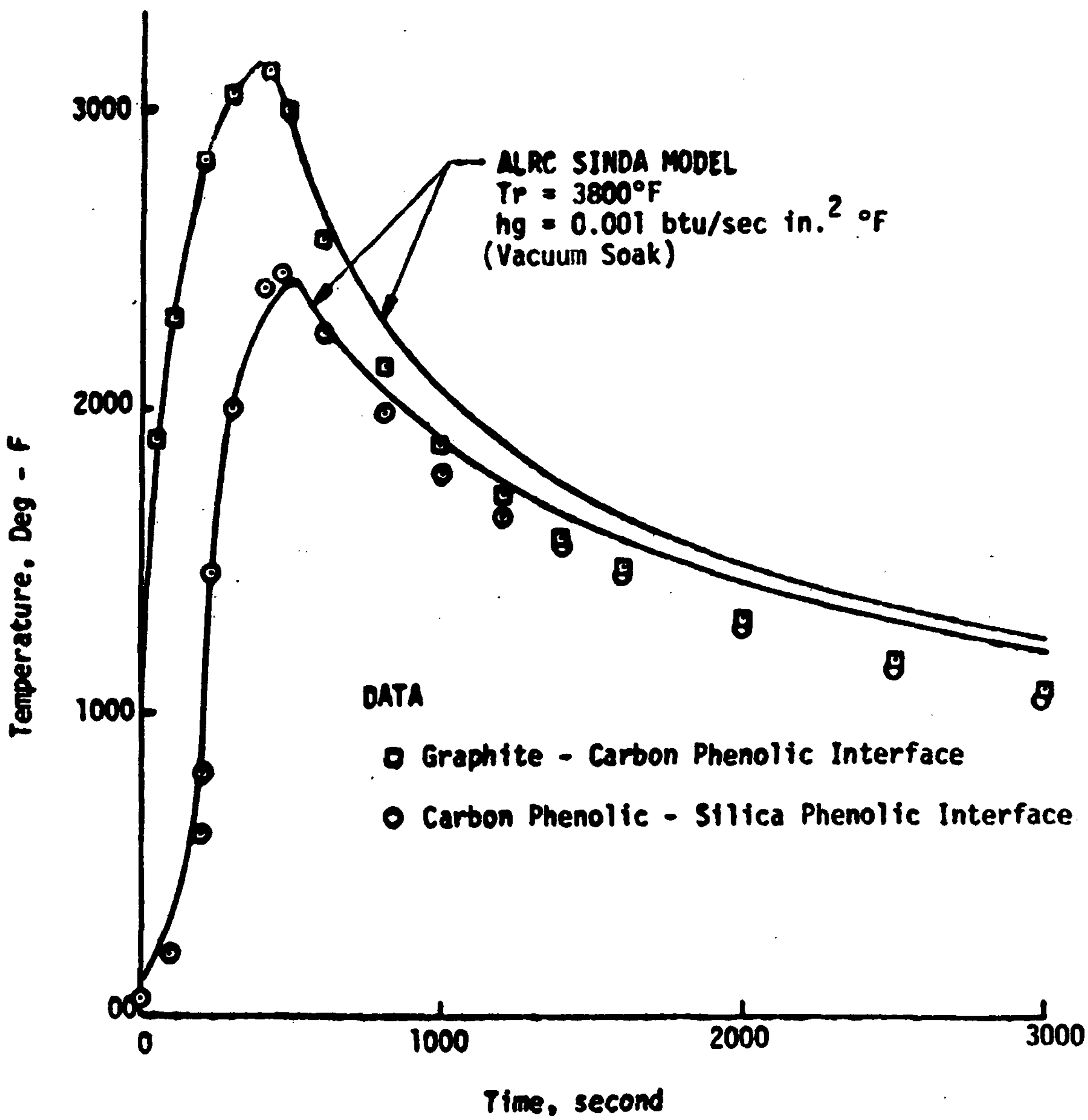


Figure 14. Correlation of ALRC's SINDA Model with JPL Test Data

Material	Laminate Properties: Temp (F)	Laminate Properties: K BTU/in-sec °F (x 10^{-6})	Laminate Properties: Temp (F)	Laminate Properties: CP ($\frac{BTU}{lb-°F}$)	Char Properties: Temp (F)	Char Properties: K ($\frac{BTU}{in.-sec\ °F}$) x 10^{-6}	Char Properties: Temp (F)	Char Properties: CP ($\frac{BTU}{lb\ °F}$)	Char Properties: Heat of Char BTU/lb	Char Properties: Char Temp (F)	Char Density (lb/in.^{3}	Laminate Density lb/in^3
AGCarb-101	70	810	70	0.160							0.048	.048
	1000	559	1000	0.380								
	2000	401	2000	0.475								
	3000	366	3000	0.500								
	4000	401	4000	0.50								
			5000	0.56								
Carbon Phenolic	100	6.75	0	0.30	0	14.5	70	0.16	1470	1000	0.040	.0515
	250	8.20	5000	0.30	500	15.0	1000	0.38				
	500	7.62			1000	18.0	2000	0.475				
	750	8.10			1500	22.0	3000	0.52				
	1000	8.50			2000	27.0	4000	0.54				
					2500	35.5	5000	0.56				
					3000	46.0						
					3500	57.5						
					4000	68.5						
Silica Phenolic	0	3.21	0	0.190	0	4.99	0	0.230	1470	1000	.0527	.0636
	400	5.69	400	0.273	300	6.92	300	0.260				
	700	6.94	700	0.337	500	7.33	500	0.310				
	1000	8.10	1000	0.400	1000	4.99	1000	0.350				
					1500	5.78	1500	0.360				
					2000	7.00	2000	0.380				
					2500	9.08	2500	0.380				
					3000	1.15	3000	0.410				
					4000	1.85	4000	0.410				
Dyna Quartz	600	1.02	600	0.248							.00358	.00358
	800	1.17	500	0.263								
	1000	1.35	1000	0.272								
	1400	1.75	1400	0.284								
	2000	2.52	2000	0.295								
	2100	2.70	2700	0.305								

Figure 15. Materials and Char Properties as a Function of Temperature

IV, B, Design Selection (cont.)

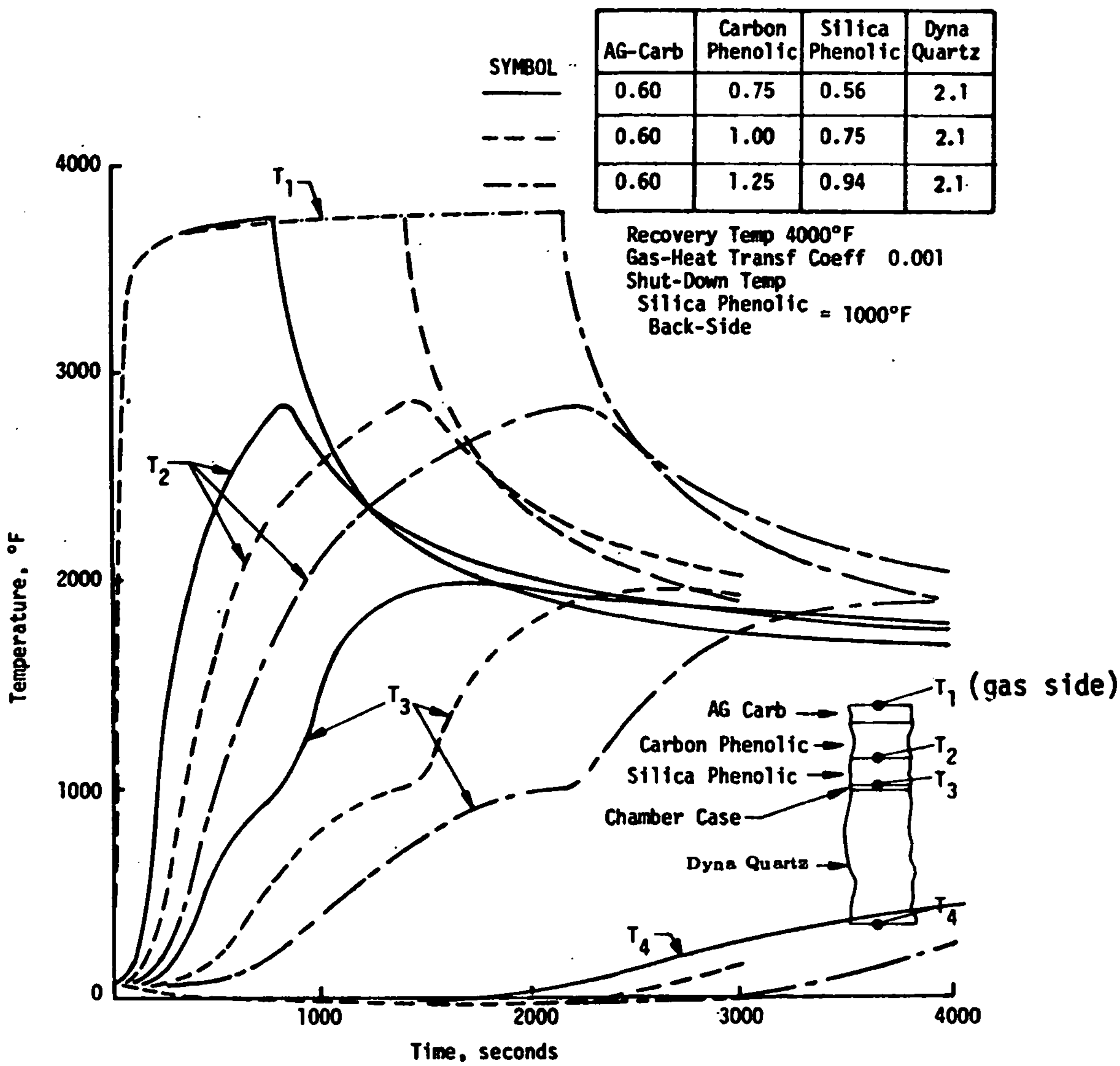
The gas side liner and material component interface temperatures of the recommended thrust chamber for the bimodal and liquid-liquid engines are shown as a function of time for various wall thicknesses in Figure 16. This data shows the thicknesses of the wall components of three engines which have firing duration capabilities of 800, 1400 and 2200 sec. In all instances, the liner's gas side requires a very short duration to approach the 4000°F recovery temperature.

The silica phenolic temperature does not exceed 2900°F during the firing or soak-out. This precludes silica melting and damage which could prevent reuse of the thrust chamber. The metal case of the chamber does not exceed 1000°F during operation.

The effect of the thickness of the silica phenolic material on the case temperature at shutdown is shown in Figure 17. This figure also identifies case soak-out temperature. It can be seen that if the shutdown temperature is held at 1000°F, the soak out temperature which is at a no load condition is less than 2000°F. This is within the capabilities of both steel and titanium. The surrounding Dynaquartz lightweight insulation holds the temperature of the thrust chamber OD to less than 800°F.

4. Divergent Nozzle Extension

Two designs for a radiation cooled nozzle extension were considered. One was a free standing columbium nozzle with an oxidation resistant coating. The other was a free standing nozzle made of a fibrous reinforced graphitic composite material. Both are mechanically attached to the aft end of the ablative thrust chamber described in the preceeding section of this report, have the same physical size and are subjected to the same thermal environment. The graphitic nozzle was selected for the baseline thrust



SYMBOL	AG-Carb	Carbon Phenolic	Silica Phenolic	Dyna Quartz
——— (solid)	0.60	0.75	0.56	2.1
— — — (dashed)	0.60	1.00	0.75	2.1
—·— (dash-dot)	0.60	1.25	0.94	2.1

Figure 16. Thrust Chamber Temperatures versus Time for Three Thrust Chamber Designs

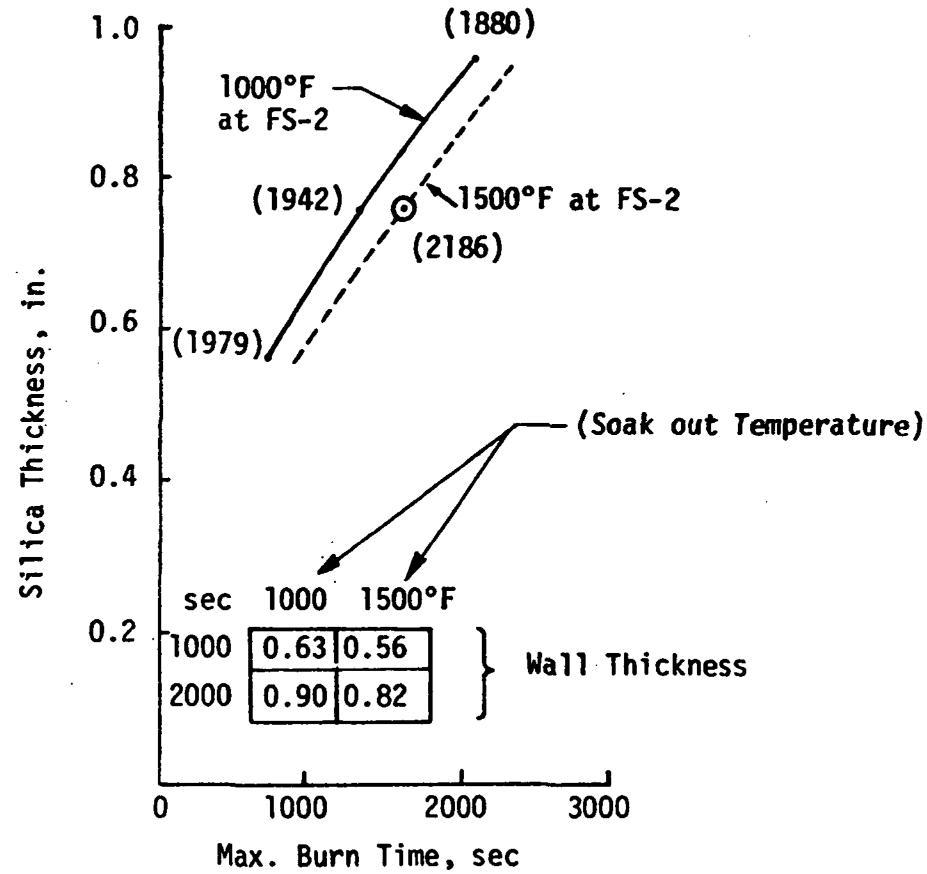


Figure 17. Silica Phenolic Thickness versus Firing Time Assuming 1000 and 1500°F Case Temperatures at Shutdown

chamber used in this weight study due to its greater development history. The same nozzle design is suitable for both the bimodal and liquid-liquid engines.

a. Development History

The successful use of a free standing graphite nozzle extension on a fluorine-hydrazine engine was first demonstrated in about 1958. Since that time similar nozzle extensions have been evaluated on both halogen/amine and earth storable propellant engines. The major development activity over the past years has been a continuing search for materials with improved mechanical properties. The earliest units used bulk graphite; the nozzles were machined from solid billets. Subsequently, vapor deposited pyrolytic graphite was utilized. The design has achieved maturity with the development of fibrous graphite reinforced composite materials. These are formed by molding or laminating carbon or graphite fibrous materials, impregnating with carbon-forming ingredients and carbonizing or graphitizing the composite. They offer the features of high strength, an ability to be fabricated in virtually any size and high thermal and mechanical shock resistance.

Free standing fibrous graphite thrust chambers and nozzle extensions have been demonstrated on a variety of halogen oxidizer liquid bipropellant engines developed by ALRC on several Air Force contracts. Currently fibrous graphite nozzle extensions are in development for several different solid propellant engines. Figure 18 illustrates a nozzle extension fabricated for a solid propellant Apogee engine. The nozzle has a thickness of 0.075 in.

The solid propellant engine rocket nozzles are generally subjected to a single relatively short duration firing. The liquid propellant nozzles have accumulated firing durations of up to 400 seconds without damage.

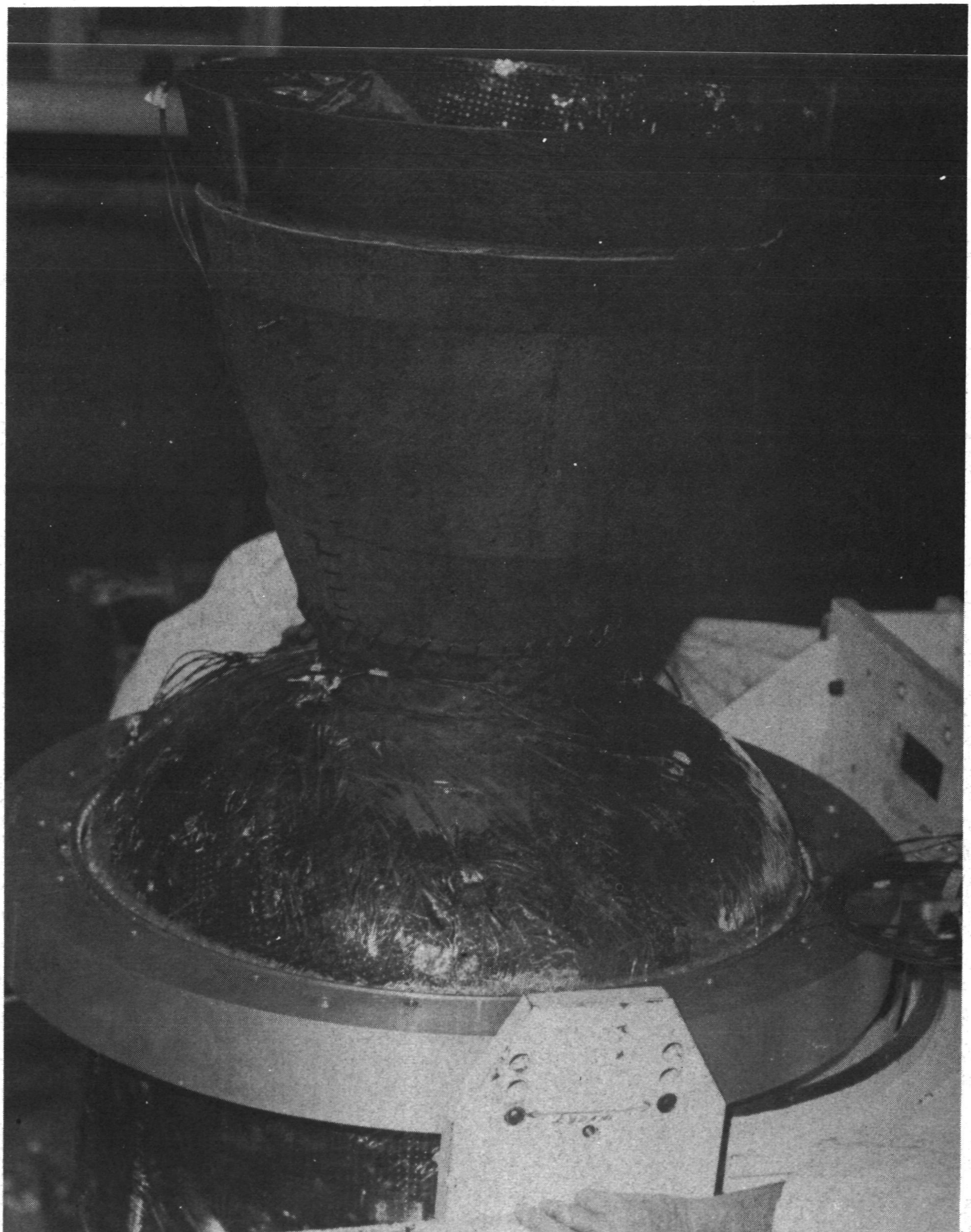


Figure 18. Solid Propellant Apogee Engine with a Fibrous Graphite Nozzle Extension

Columbium nozzle extensions have also been tested with fluorine/amine propellant systems. The most recent data was obtained on an AFRPL sponsored program[1] in 1967. The columbium nozzle tested was made from C-103 alloy and operated at a temperature of about 2400°F. It was fired for an accumulated duration of 200 sec. Posttest evaluation of two different silicide coatings showed limited coating oxidation and cracking. It was concluded that the nozzle design was adequate for the program's 600 sec duration requirement. There is no data which indicates the same design would be capable of 2000 sec of operation.

b. Selected Design

The free standing fibrous graphite nozzle extension design shown in Figures 1 and 2 is suitable for both the liquid-liquid and bimodal engines. The selected nozzle extension-thrust chamber design has the following features:

The nozzle extension is removable. Consideration was given to making the nozzle extension and chamber liner monolithic. This was rejected because the separate nozzle extension facilitates both manufacture and handling.

It has 0.075 in. thick wall. This is sufficiently thick that fabrication problems are minimized while avoiding excessive weight. An equivalent weight columbium nozzle would have a 0.010 inch thick wall.

A recessed attachment flange provides isolation of the flange from the combustion products. This reduces the flange temperature and allows the thermal gradient to occur over several inches of the nozzle to preclude high bending stresses at the attachment.

1 Contract F04611-67-C-0003 Development and Demonstration of Ablative Thrust Chamber Assemblies using LF_2/N_2H_4 Blend Propellants. Final Report (AFRPL-TR-69-2) by R. C. Schindler and H. V. Kiser.

A Marman type clamp and Graphfoil seal allow thermal discontinuities between the nozzle extension and chamber flange by permitting radial motion of the flange surfaces.

5. Gimbal Ring and Thrust Mount

The throat plane mounted gimbal shown in Figures 1 and 2 utilizes a rectangular cross section gimbal ring that is secured to the conical thrust mount by two bolts through self aligning, Teflon-lined spherical bearings retained in the gimbal ring with threaded retainers. One of the bearings is fixed at the inner race by the bolt passing through it, while the other bearing is free to slide, thus allowing for thermal expansion of the thrust mount. The gimbal ring can be secured to the spacecraft by means of bearing housings which retain the bearings and bolt to the vehicle structure. The gimbal ring assembly permits the engine assembly to gimbal upon receiving an applied force from the gimbal actuators for directing the thrust.

The thrust mount is a conical structure which extends from the gimbal ring to the injector-chamber flange area. It is designed to be self supporting to avoid the need for sway braces which would contact the thrust chamber pressure vessel. The thrust mount has a stiffener ring located adjacent to the two ears which engage to gimbal ring to prevent local deformation of the thin titanium sheet metal cone due to load concentrations.

The same gimbal ring and thrust mount design is suitable for the bimodal and liquid-liquid engine designs.

V. PERFORMANCE ANALYSIS

A. APPROACH

The performance analysis effort was structured to compare the delivered specific impulse of the two different LF_2/N_2H_4 engine concepts over a range of operating and design conditions. The first phase of the analysis consisted of a review of liquid-liquid and bimodal injector experience and the selection of specific design configurations to be used as the basis for detailed design and performance analyses. This review resulted in the selection of a like-doublet element injector for the liquid-liquid engine and a hub-fed tubular vane injector for the bimodal engine. Details of this selection are provided in Section IV,B,2 of this report.

Following the selection of an injector configuration for each engine concept, an analysis of existing experimental data was conducted to determine the current performance efficiency and performance limitations of each design. These data provided the basis for a projection of the performance level each injector could achieve through a limited development program. Details of this analysis are presented in the following section.

Next a parametric performance analysis computer program was constructed to calculate the performance and envelope dimensions over the desired parametric range for the bimodal and liquid-liquid engines. The parametric analysis computer program was built upon the procedures specified by the JANNAF Liquid Rocket Performance Subcommittee[1] and is described in Section V,C of this report. The parametric analysis computer program was utilized to calculate the performance and envelope for 810 specific points (includes the range of operating and design points for both engine concepts) and to generate 108 plots of delivered specific impulse as a function of mixture ratio and engine length. The parametric performance analysis results are discussed in Section V,D. Plots and tabulations of the data are presented in Appendix A.

(1) Pieper, J. L., ICRPG Liquid Propellant Thrust Chamber Performance Evaluation Manual, CPIA Pub No. 178, Prepared for the ICRPG Performance Standardization Group, 30 September 1968.

V, Performance Analysis (cont.)

B. INJECTOR EFFICIENCY CHARACTERIZATION

Data from both like-doublet and bimodal injector testing was analyzed to determine their respective energy release efficiencies at their current state of development. The performance losses which were considered in this study are identified in Figure 19 which also identifies the engine operating parameters which influence the losses and the analytical models used in their definition.

Sea level test data (corrected to vacuum conditions) obtained with the like-doublet liquid-liquid injector are shown in Figure 20. These data were obtained from JPL sea level testing of an engine having a nozzle area ratio of 2.5:1. This figure presents the ODE, ODK and "perfect" injector performance in addition to the measured test data. The "perfect" injector performance would be achieved if there were no energy release loss (ERL); all the other performance losses described in Figure 19 would apply.

Test data obtained from the fire testing of ALRC's bimodal tubular vane injector are presented in Figure 21 and are arranged in a manner similar to the data of Figure 20. Since the data were obtained from sea level testing with a nozzle having an area ratio of 1.5:1, the absolute specific impulse values can not be directly compared with the values shown in Figure 20 which were obtained with a 2.5/1 nozzle. The comparative performance of the liquid-liquid and bimodal injectors is shown in terms of the energy release efficiency, (ERE) in Figure 22.

The analysis results (Ref. Figure 22) indicate that the like-doublet and tubular vane injectors experimentally evaluated in liquid-liquid and bimodal engines respectively have energy release efficiencies (ERE) of approximately 97.5% and 97.8%, at a mixture ratio of 1.6 using chamber designs with L* values of 24 and 10.2 inches, respectively. A $\pm$ 0.5% band should be

- **ENERGY RELEASE LOSS**
  - DUE TO PROPELLANT VAPORIZATION LIMITATIONS
    - MAY CAUSE SHIFT IN OPTIMUM MIXTURE RATIO COMPARES TO IDEAL PERFORMANCE
    - MAY BE COMPENSATED FOR BY INCREASED CHAMBER LENGTH (EVALUATED USING PRIEM GENERALIZED LENGTH MODEL)
  - DUE TO PROPELLANT MIXING LIMITATIONS
    - MAY CAUSE SHIFT IN OPTIMUM MIXTURE RATIO COMPARED TO IDEAL PERFORMANCE
    - INCREASING CHAMBER LENGTH WILL NOT SIGNIFICANTLY DECREASE LOSS (EVALUATED EMPIRICALLY)
- **FILM COOLING LOSS**
  - LOSS DUE TO FILM OR BARRIER COOLING, (EVALUATED FROM STREAM TUBE ANALYSIS)
- **DIVERGENCE LOSS**
  - INFLUENCE BY NOZZLE CONTOUR, AREA RATIO, AND GAS PROPERTIES
    - ANALYSES METHOD - RAO DESIGN CHARTS
- **BOUNDARY LAYER LOSS**
  - INFLUENCED BY ENGINE SURFACE AREA, HEAT TRANSFER, THRUST LEVEL AND GAS PROPERTIES
    - ANALYSES METHOD - TURBULENT BOUNDARY LAYER PROGRAM
- **KINETIC LOSS**
  - INFLUENCED BY MIXTURE RATIO, CHAMBER PRESSURE AND THRUST LEVEL
    - ANALYSIS METHOD - ONE DIMENSIONAL KINETICS PROGRAM

Figure 19. Performance Losses Description

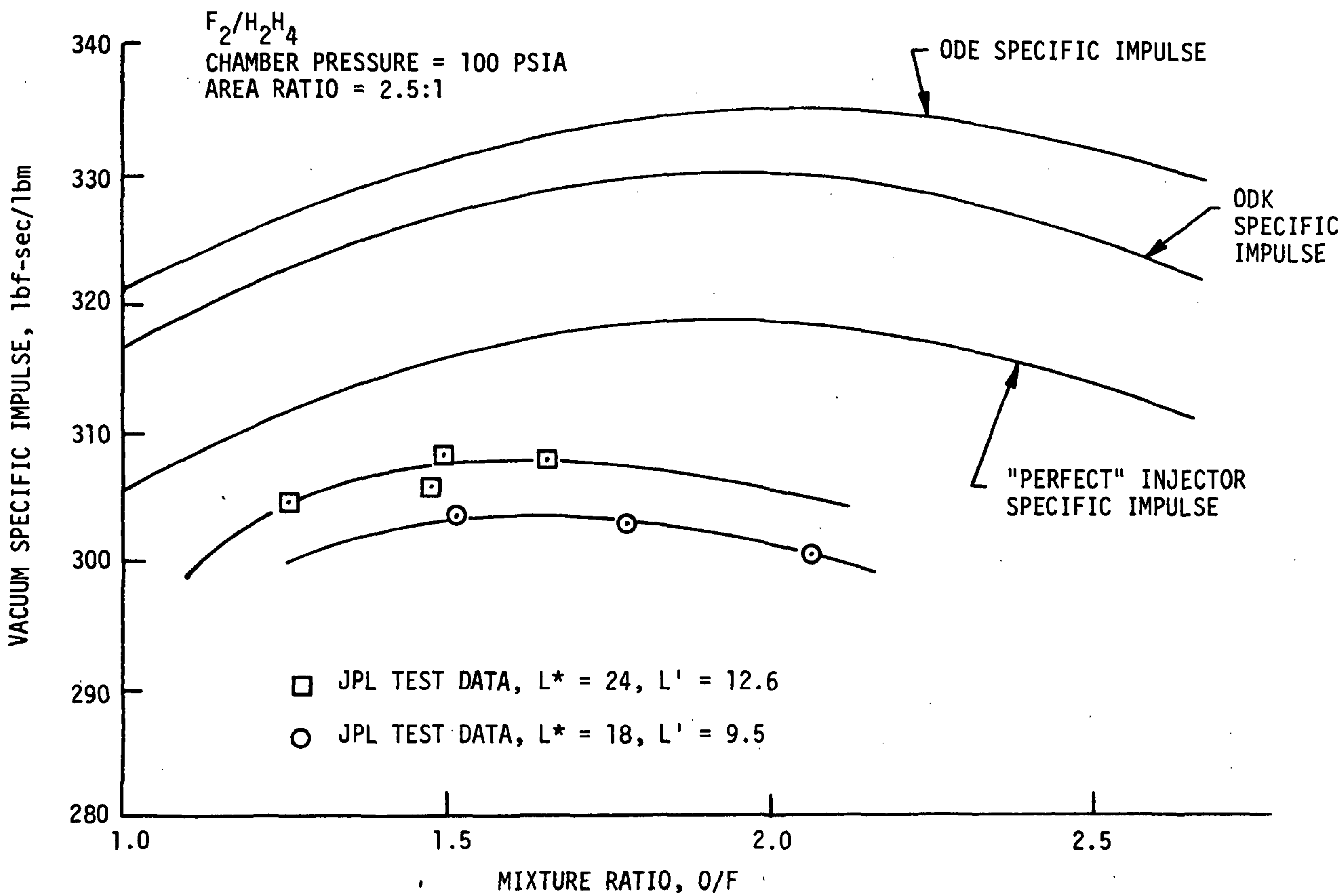


Figure 20. Like-Doublet Injector Performance

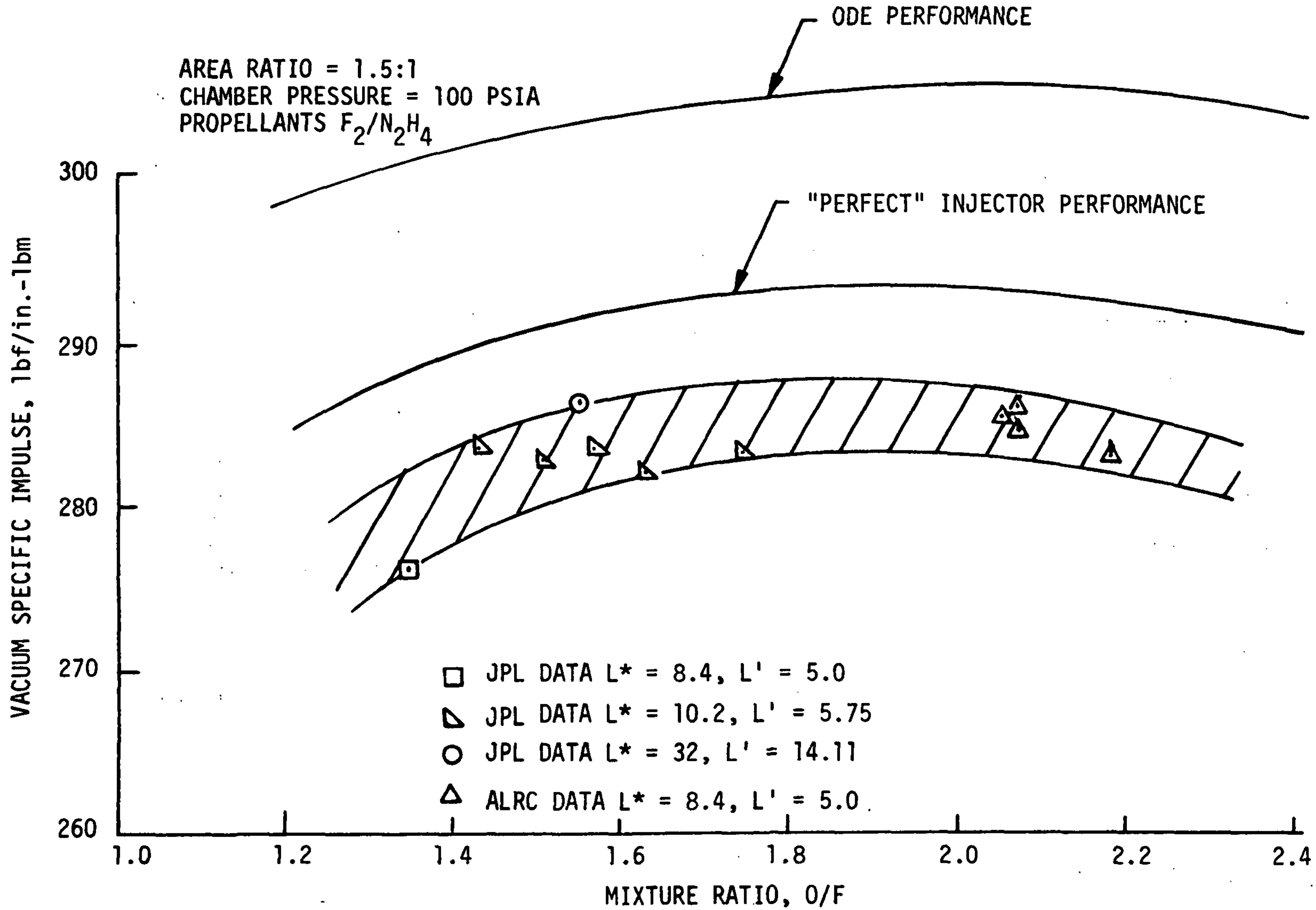


Figure 21. Bimodal Injector Performance Summary

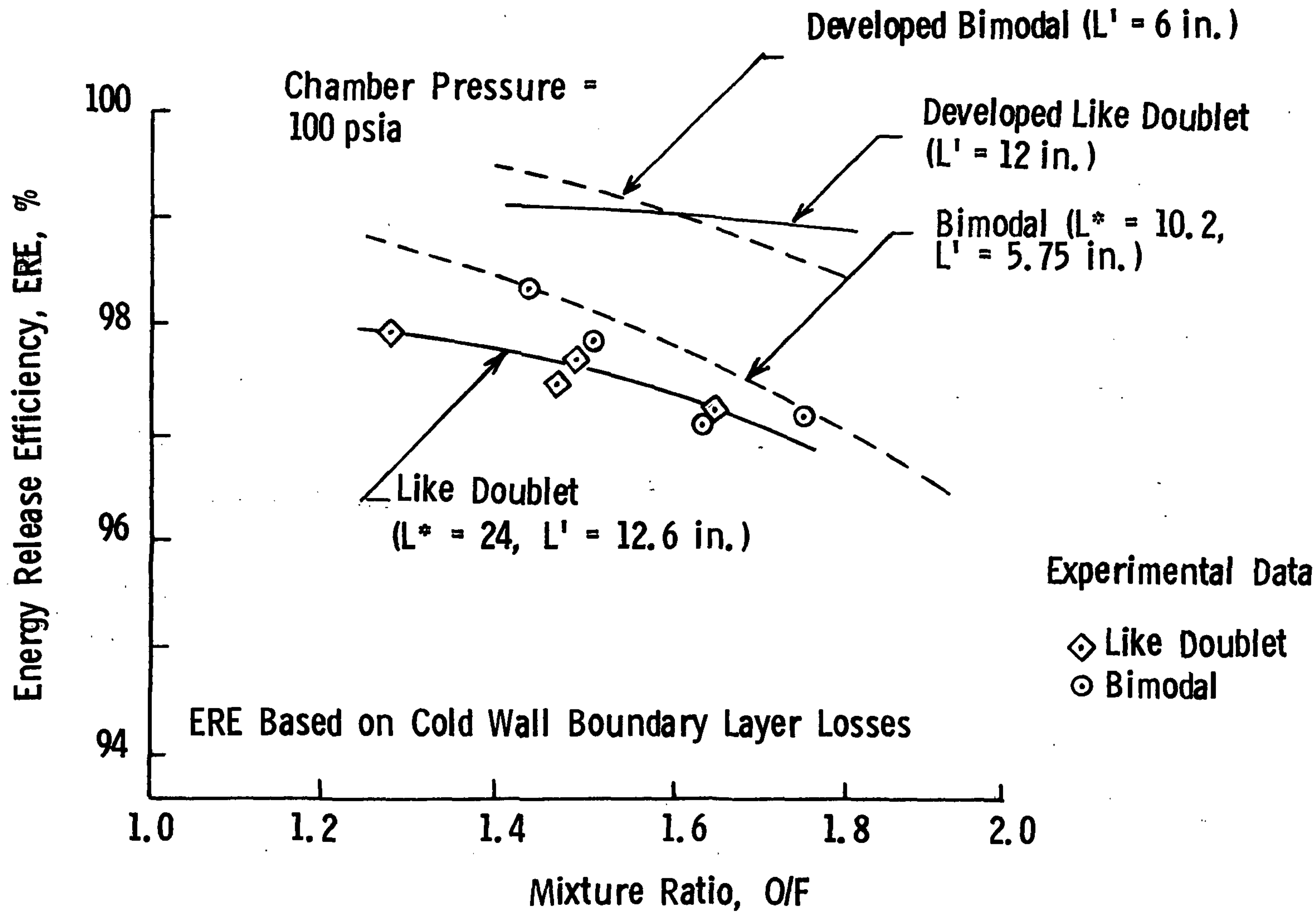


Figure 22. ERE versus MR for Liquid-Liquid and Bimodal Injectors

V, B, Injector Efficiency Characterization (cont.)

imposed on the measured ERE values of Figure 21 to reflect the uncertainty in the test data and simplified analysis procedure. The energy release losses (ERL) for the bimodal unit are attributed to propellant mixing limitations. A combination of vaporization and mixing limitations account for the liquid-liquid injector's ERL. The anticipated ERE of each injector concept at the conclusion of limited development programs is estimated to be 99% at the above defined L* values. Present and anticipated performance values are summarized below.

	Test Data			Anticipated
	ERE%	L', in.	L*, in.	ERE%
Bimodal	97.8 ± 0.5	5.75	10.2	99 ± 0.5
Liquid-Liquid	97.5 ± 0.5	12.6	24	99 ± 0.5

The liquid-liquid engine's performance is more sensitive to chamber length variation than that of the bimodal engine because of fuel vaporization limitation effects.

The major development required to increase the ERE of the bimodal injector is to improve its mixture ratio distribution. This would require the use of flow turning vanes (ref. Figure 2) to insure proper fuel flow distribution and the relocation and resizing of the oxidizer orifices to avoid oxidizer concentration adjacent to the chamber wall. The basic design of the monopropellant reactor and tubular vane oxidizer injector would not be changed.

Since the like-doublet injector performance is basically fuel vaporization limited, a development program for this injector concept would concentrate on improvements in the fuel vaporization efficiency. This could be accomplished through a reduction in the element orifice size thereby decreasing the injector thrust-per-element (F/E). The like-doublet injector

V, B, Injector Efficiency Characterization (cont.)

tested by JPL and used in the performance analysis has a thrust-per-element of 25. It is estimated (through a fuel vaporization analysis), that the energy release efficiency of the like-doublet injector design could be increased to 99% within the 12 in. L' combustion chamber by decreasing the F/E to approximately 14. This is a lower limit for this injector concept as a result of both a limiting hole size (D_{Fuel} = 0.013 in.) and injector manifold limitations (element density). Further performance improvements with liquid-liquid injection concept would require a change in the basic injector concept.

The utilization of the platelet injector concept (Ref. Section III,C of this report) could provide the required low thrust-per-element for the achievement of high performance efficiency (99% ERE) in a significantly shorter chamber (L' = 6 to 8 in.). Although it is likely that an acoustic damper would be required to insure dynamic stability of the fine patterned liquid-liquid injector its use would have little effect on the design of the injector. Fire testing would be necessary to verify the selected acoustic cavity design.

C. PARAMETRIC ANALYSIS METHOD

The parametric performance analysis was accomplished using a computer model constructed to meet the comparison study's specific requirements. It was built upon the procedures specified by the JANNAF Liquid Rocket Performance Subcommittee[(2)] and was a modification of a computer model formulated for another engine study (Contract NAS 8-29806)[(3)]. The JANNAF Subcommittee has recommended two performance analysis methods. This standard procedure which utilizes the best available analytical procedure is best suited to single point performance analysis of existing engine systems. The second

(2) Ibid; Page 42.
(3) Final Report, "Space Tug Storable Engine Study", Volume II, Engine Design and Performance Characteristics", Contract NAS 8-29806, Report PPD 396; DR-MA-03.

V, C, Parametric Analysis Method (cont.)

method is a simplified procedure which utilizes design chart data and lower cost computer programs. It is designed for the parametric analysis of engine systems and was ideally suited to this study.

The program calculates delivered thrust chamber performance and the engine envelope as a function of engine chamber pressure (P_c), area ratio (EPS), mixture ratio (O/F), chamber length (L'), and chamber contraction ratio (CR). To accomplish this wide-range, parametric analysis with a minimum cost, the JANNAF procedures have been expanded to include: (1) vaporization and mixing limited energy release loss, (2) ODE and ODK I_{sp} and C* data tabulations as a function of O/F, P_c and EPS, (3) injector design limits, and (4) envelope design data.

The parametric analysis computer program calculated the performance and engine parameters for the bimodal and liquid-liquid engines over the specified range of design and operating conditions shown in the following tabulation.

FLUORINE/HYDRAZINE ENGINE COMPARISON PARAMETRIC RANGES

Engine Design:	(2); Bimodal and Liquid-Liquid
Thrust Level:	(1); 600 lbf
Chamber Pressure:	(3); 80, 120, 200 psia
Mixture Ratio:	(5); 1.4, 1.5, 1.6, 1.7, 1.8
Area Ratio:	(3); 40, 60, 80
Contraction Ratio:	(3); 1.5, 2.5, 5.0 (Bimodal), 1.5, 2.25, 5.0 (Liquid-Liquid)
Chamber Length:	(3); 6, 12, 15 in.

Delivered engine performance and envelope are determined for any set of design and operating conditions through the evaluation of the one-dimensional equilibrium (ODE) specific impulse and the appropriate performance losses. The engine envelope is determined from the calculated performance level and the nozzle design and chamber length requirements and specific operating conditions. A brief description of the methods used to evaluate the above parameters follows.

1. One Dimensional Equilibrium (ODE) and One Dimensional Kinetic (ODK) Performance

The ODE and ODK I_{sp} and C* are included in block data form in a subroutine. The data were calculated using the JANNAF approved ODK/ODE computer program. A parametric evaluation of the ODE and ODK I_{sp} and C* over a wide range of nozzle expansion ratios, O/F ratios, and chamber pressures was accomplished and its results are included in the evaluation program. The ODE I_{sp} is included in the parametric analysis tables of Appendix A under the heading ISPT.

2. Divergence Loss

The nozzle divergence loss (% DL) is evaluated for Rao (Bell) nozzles using design charts similar to those presented in Appendix A of CPIA No. 178[1]. Data from these charts are contained in block data format in a subroutine which supplies the nozzle divergency efficiency and nozzle length for a specified nozzle area ratio and length ratio. The divergence efficiency as a function of length and area ratio is determined from a method-of-characteristics computer program using the design technique developed by Rao[4].

Three nozzle design options were included in the parametric analysis computer program to provide flexibility over the broad parametric ranges. The first two options provided a nozzle design producing maximum thrust for either a specified area ratio (option 1) or a specified nozzle

(4) Pieper, J. L., and Hurr, G. B., Computer Program for Calculating Rao Optimum Nozzle Contours, ALRC Report No. 9600:M-044, September 1971.

V, C, Parametric Analysis Method (cont.)

expansion length (Option 2). The third option provided optimum nozzle designs for a specified nozzle exit point (i.e., area ratio and length).

3. Boundary Layer Performance Loss

The boundary layer performance loss (% BLL) is evaluated using the Design Charts presented in Appendix B of CPIA No. 178[1]. The Design Chart data are included in block data format in a boundary layer loss subroutine of the computer program. Inputs to the subroutine include the nozzle area ratio and throat radius, chamber pressure, gamma (1.30), nozzle exit angle, CSTAR, and wall temperature ratio (0.6).

4. Fuel Film Cooling Loss

The fuel film cooling loss (% FCL) is calculated using a two stream tube model. This performance loss is calculated by subtracting the mass flow rate weighted sum of the core I_{sp} and the monopropellant film cooling layer I_{sp} from the I_{sp} at the engine overall O/F.

5. Energy Release Loss

The energy release loss (% ERL) is based on the empirical energy release performance loss mechanisms described in Section V,B. Thus, the bimodal engine energy release loss is mixing limited and is independent of chamber length over the range included in this study. The liquid-liquid engine energy release loss, on the other hand is vaporization limited and thus varies significantly with chamber length and thrust-per-element.

The fuel and oxidizer vaporization efficiencies of the like-doublet injector were calculated using the generalized length procedure

V, C, Parametric Analysis Method (cont.)

developed by Priem[5]. This procedure permits chamber design parameters such as contraction ratio (CR) and chamber length (L') to be input into an analysis which calculates directly the energy release loss (ERL) resulting from incomplete vaporization. This analysis correlated well with the available experimental data as discussed in the previous section. The propellant drop size is determined from the correlations developed by Preim and is a function of the propellant properties (surface tension, viscosity, density), orifice size and injection velocity. Injection design limits are also imposed. These limits determined the number of elements and element size as a function of the injector size and the specified injector stiffness (ΔP inj = 65% of P_c). This criterium limited the number of injection elements/unit area to 6.8 like-doublets/in.^{2} and the minimum injection orifice size (D_{min}) to 0.013 in.

D. PERFORMANCE ANALYSIS RESULTS

The performance analysis results of the Fluorine/Hydrazine Engine Comparison Study are tabulated in Table Sets A and B of Appendix A for the liquid-liquid and bimodal engines, respectively. Included in each table are the estimated delivered performance, performance losses, and engine envelope dimensions for 405 specific design points which cover the range of parametric conditions included in the study (reference Section V,C of this report). The calculated delivered specific impulse is also shown as a function of mixture ratio or total engine length in the Figures of Appendix A. Figure Set A shows the variation of delivered I_{sp} with mixture ratio for the liquid-liquid engine. Figure Set B contains similar plots of delivered specific impulse for the bimodal engine. The variation in delivered specific impulse with engine length is shown in Figure Set C for the liquid-liquid engine and in Figure Set D for the bimodal engine. Note that the performance increase with engine

(5) Priem, R. J., and Heidmann, F. M., Propellant Vaporization as a Design Criterion for Rocket-Engine Combustion Chambers, NASA TR R-67, 1960.

V, D, Performance Analysis Results (cont.)

length as shown in Figures Sets C and D is obtained by increasing the nozzle expansion area ratio over the range from 40-80. Thus the data included in Figure Sets C and D are essentially cross plots of the data presented in Figure Sets A and B.

A summary of the performance results is shown in Figure 23. This summary indicates that at the nominal design conditions the bimodal engine specific impulse is slightly higher (~0.5%) than the specific impulse of the liquid-liquid engine while its chamber length is significantly shorter (50%). As a result, the bimodal engine weight is significantly lower (25%) than the liquid-liquid engine weight. On the other hand, if the liquid-liquid engine is designed with the shorter chamber its performance decreases approximately 13 sec and thus is nearly 4% lower than performance of a bimodal engine of the same length.

PROPELLANTS: F_2/N_2H_4
THRUST: 600 lbf

	DEVELOPED BIMODE	DEVELOPED LIQUID/LIQUID
RANGE OF ISP (SEC)	363-391	353-390
NOMINAL ISP (SEC)	382	380
NOMINAL CONDITIONS:		
L' (IN.)	6.0	12.0
P_C (PSIA)	120	120
CR	2.50	2.25
AREA RATIO	60	60
MIXTURE RATIO	1.7	1.7
ENGINE LENGTH (IN.)	27	32
ENGINE WEIGHT (LBM)	36	48
DURATION (SEC)	2000	2000

Figure 23. Performance Forecast Summary

VI. WEIGHT ANALYSIS

The subject program was designed to provide a weight comparison between the liquid-liquid and bimodal engines over a range of chamber pressures, nozzle area ratios and operating durations as combustion chamber length and contraction ratios were varied. This was accomplished by selecting the baseline engine designs shown in Figures 1 and 2 and then varying the necessary dimensions to achieve the range of design parameters.

The weight analysis results provide an accurate comparison of the two engine design concepts although the absolute weight values for any particular design point may not be optimum. This is due to the fact that thermal and stress analyses of the subject engines were limited to the baseline designs and were conducted to insure absence of gross errors rather than for design optimization. For example, the wall thickness of the ablative chamber is based on a one dimensional analysis at the throat station and the stress analysis did not consider gimbal loads.

The weight data which follows was obtained from the calculation of engine weights for units which have operating durations of 800 and 2000 sec. The linear relation of engine weight and duration was verified by the thermal analyses which selected wall thicknesses for engines with operating durations of 800, 1400 and 2200 seconds. This data is shown in Figure 24.

The difference in the injector to throat distance (L') of the bimodal and liquid-liquid engines could result in detail differences in the chamber designs of the two units. This is due to the fact that the longer unit can accumulate a greater dimensional mismatch between the chamber liner and metal shell as a result of the difference in the coefficients of thermal expansion for the silica phenolic liner and the titanium case. There are two possible solutions to this problem. One is to further recess the liquid-liquid injector and allow a forward end gap for the axial growth of the liner relative to the metal case. The other is to use some type of metal shell to ablative liner

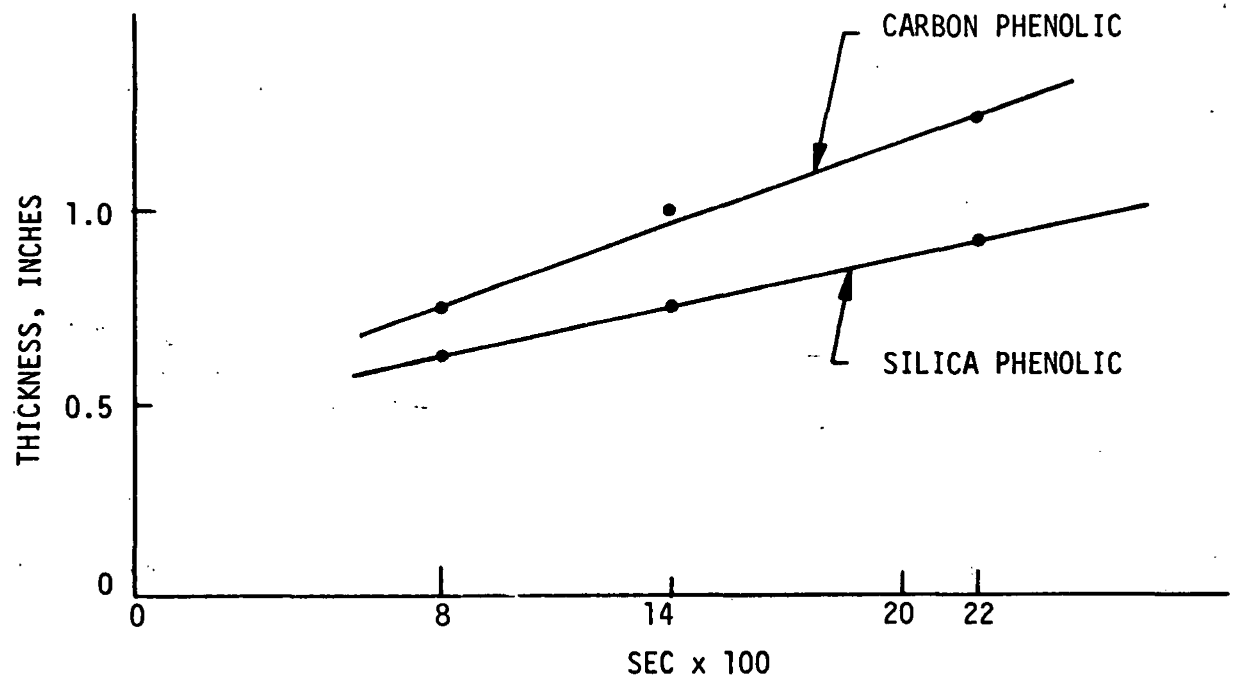


Figure 24. Wall Thickness versus Duration

interlock at the upstream end of the unit to reduce the effective length over which the thermal expansion occurs. The latter solution would require that the case be oversize relative to the liner downstream of the interlock.

Neither design option has a measurable impact on the calculated chamber weights.

A. LIQUID-LIQUID ENGINE WEIGHT

The liquid-liquid engine's performance is vaporization limited due to the fuel's low vapor pressure. The result is that a longer combustion chamber is required to achieve an ERE equivalent to that of the bimodal engine. The longer combustion chamber incur two penalties. One is that it weighs more. The other is that more fuel film coolant is necessary to maintain the selected 4000°F throat wall temperature.

The liquid-liquid engine is also sensitive to contraction ratio. Unlike the bimode engine increased contraction ratio results in improved performance. This is due to an increase in element quantity with an attendant decrease in orifice size (reference Section V,C,5 of this report). As a result, the liquid-liquid engine weight studies address chamber length and contraction ratio variations.

Engine weight versus chamber pressure is presented in Figure 25, 26 and 27 for chamber lengths of 6.0, 12.0 and 15.0 in., respectively. All data is presented for contraction ratios of 1.5, 2.25 and 5.0 and area ratios of 40, 60 and 80. As with the bimodal engine, the larger contraction ratio results in increased weight. This effect is compounded at the longer chamber lengths.

The effect of operating duration on engine weight is shown in Figures 28, 30 and 32 as contraction ratio (Ac/At), injector to throat

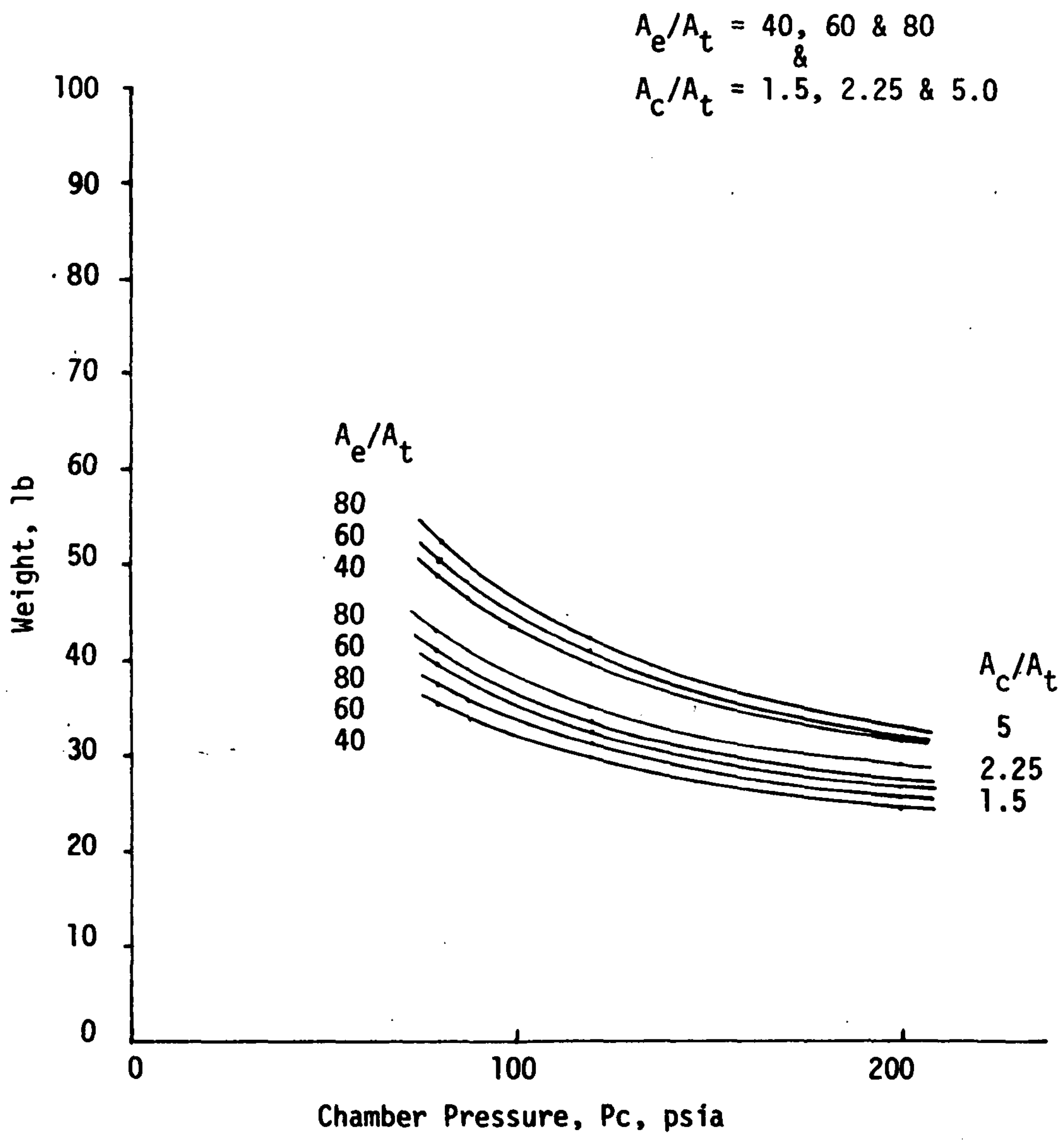


Figure 25. Weight versus P_c for Liquid-Liquid Engines with L' = 6 In.

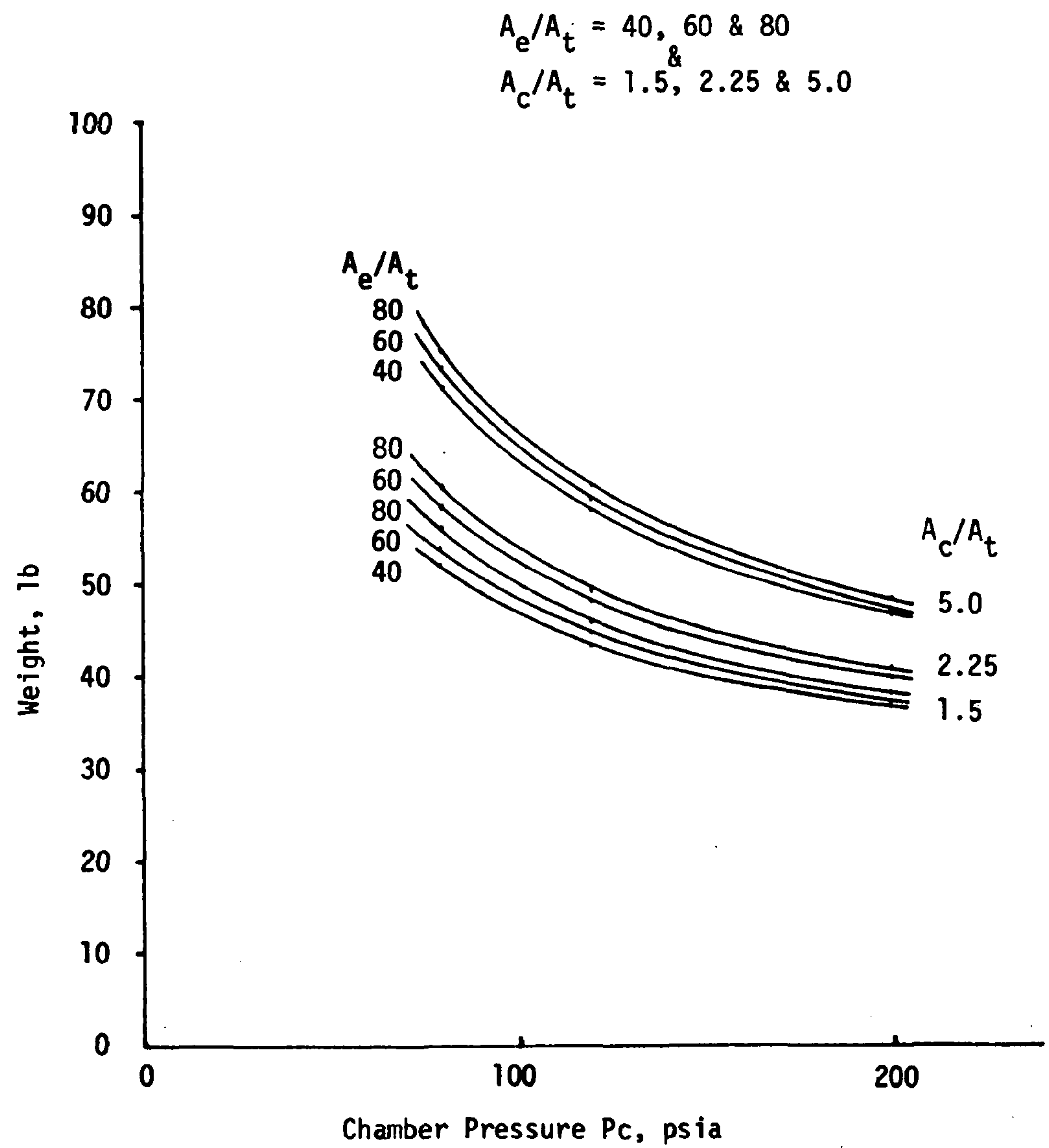


Figure 26. Weight versus P_c for Liquid-Liquid Engines with L' = 12 In.

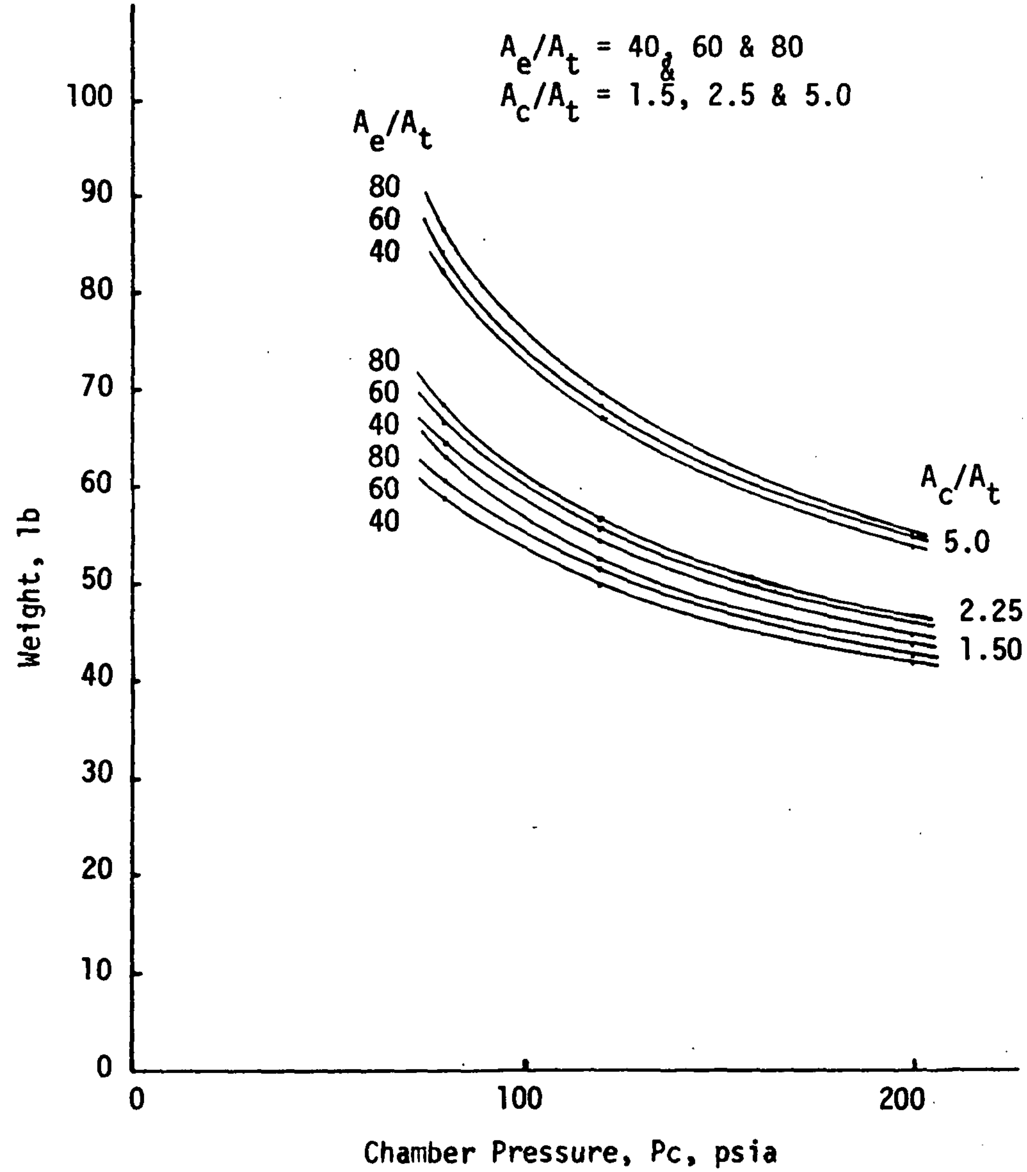


Figure 27. Weight versus P_c for Liquid-Liquid Engines with L' = 15 In.

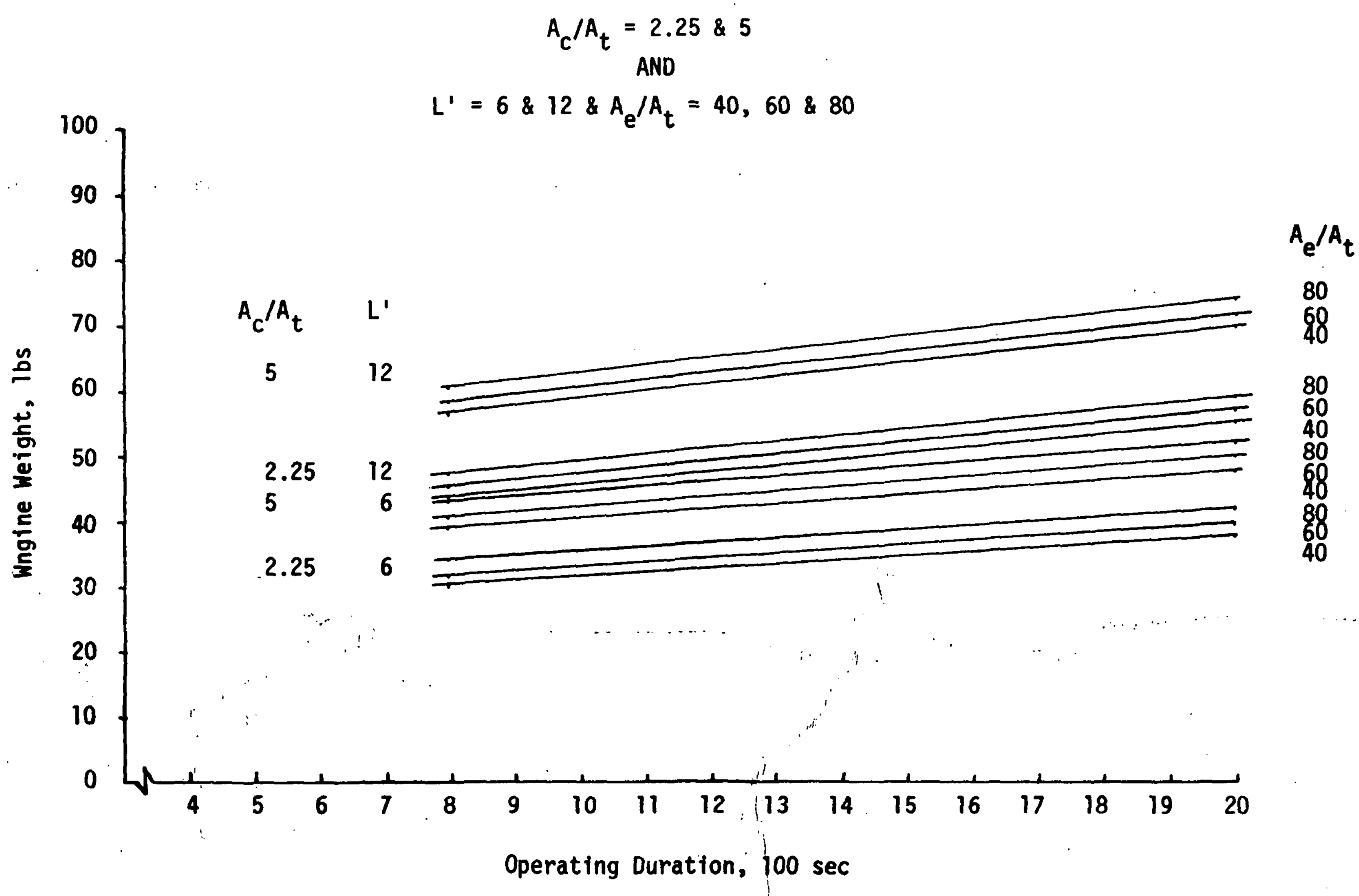


Figure 28. Weight versus Duration for Liquid-Liquid Engines at P_c = 80 psia

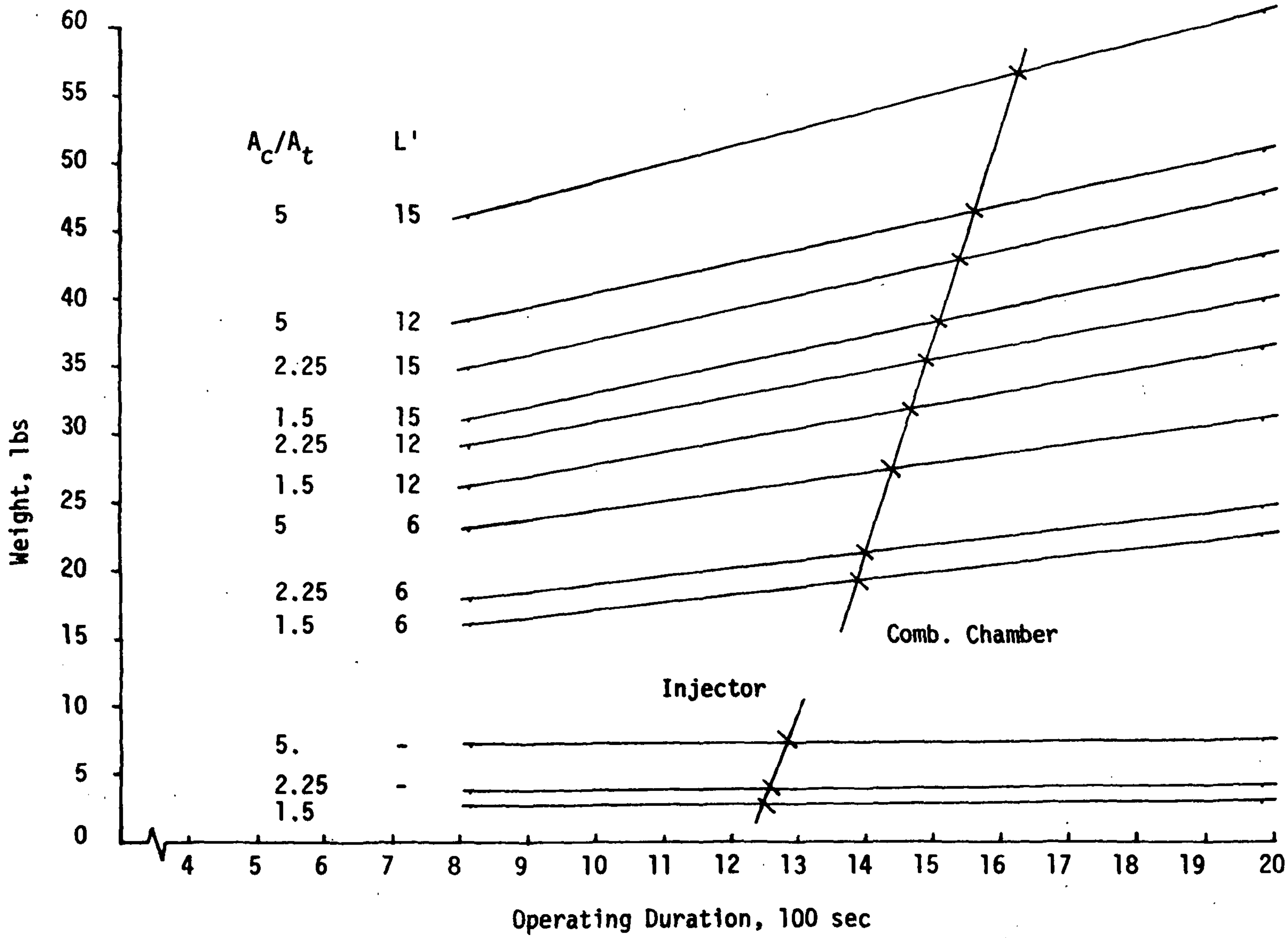


Figure 29. Injector and Chamber Weight versus Duration for Liquid-Liquid Engines at P_c = 80 psia

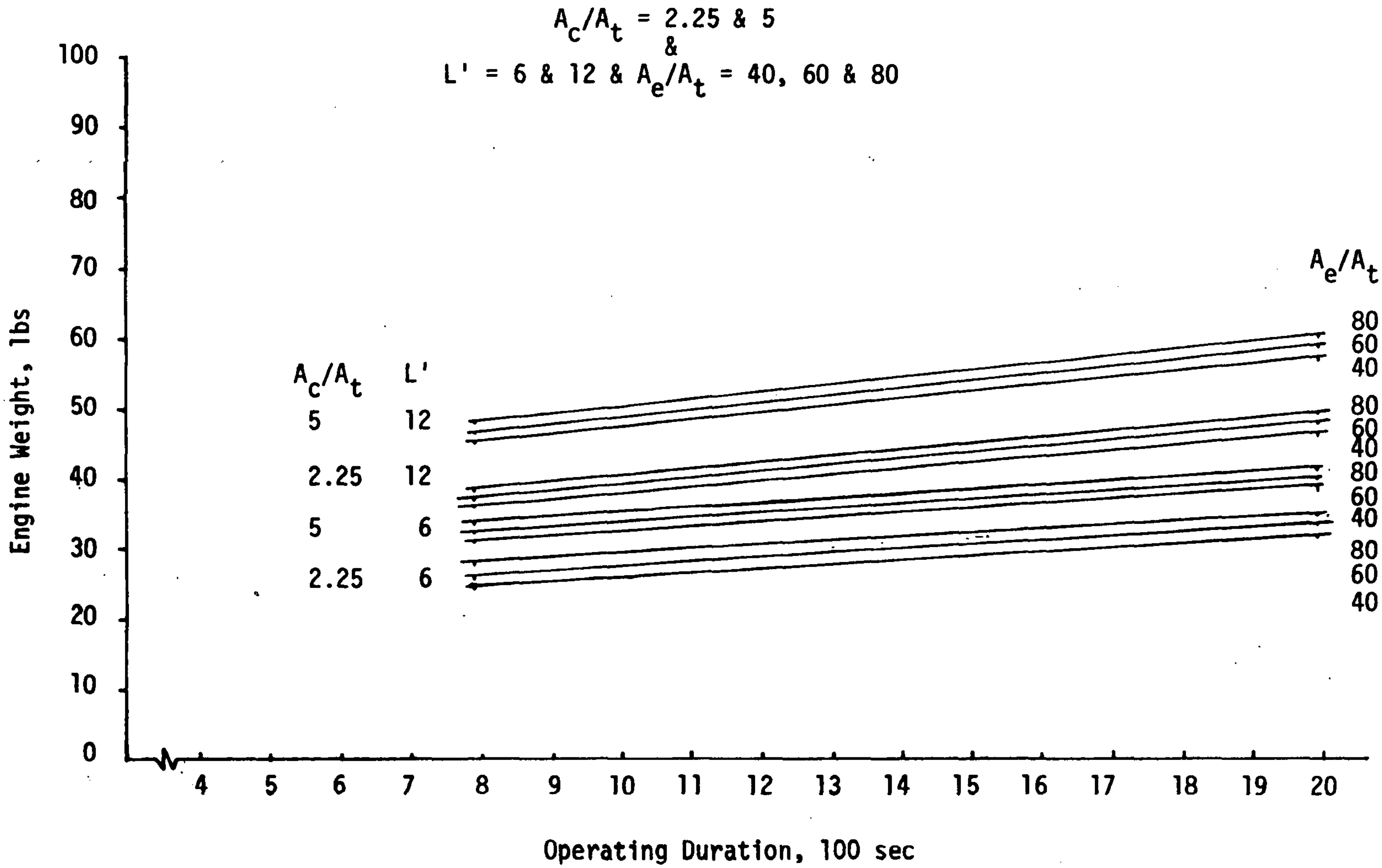


Figure 30. Weight versus Duration for Liquid-Liquid Engines at P_c = 120 psia

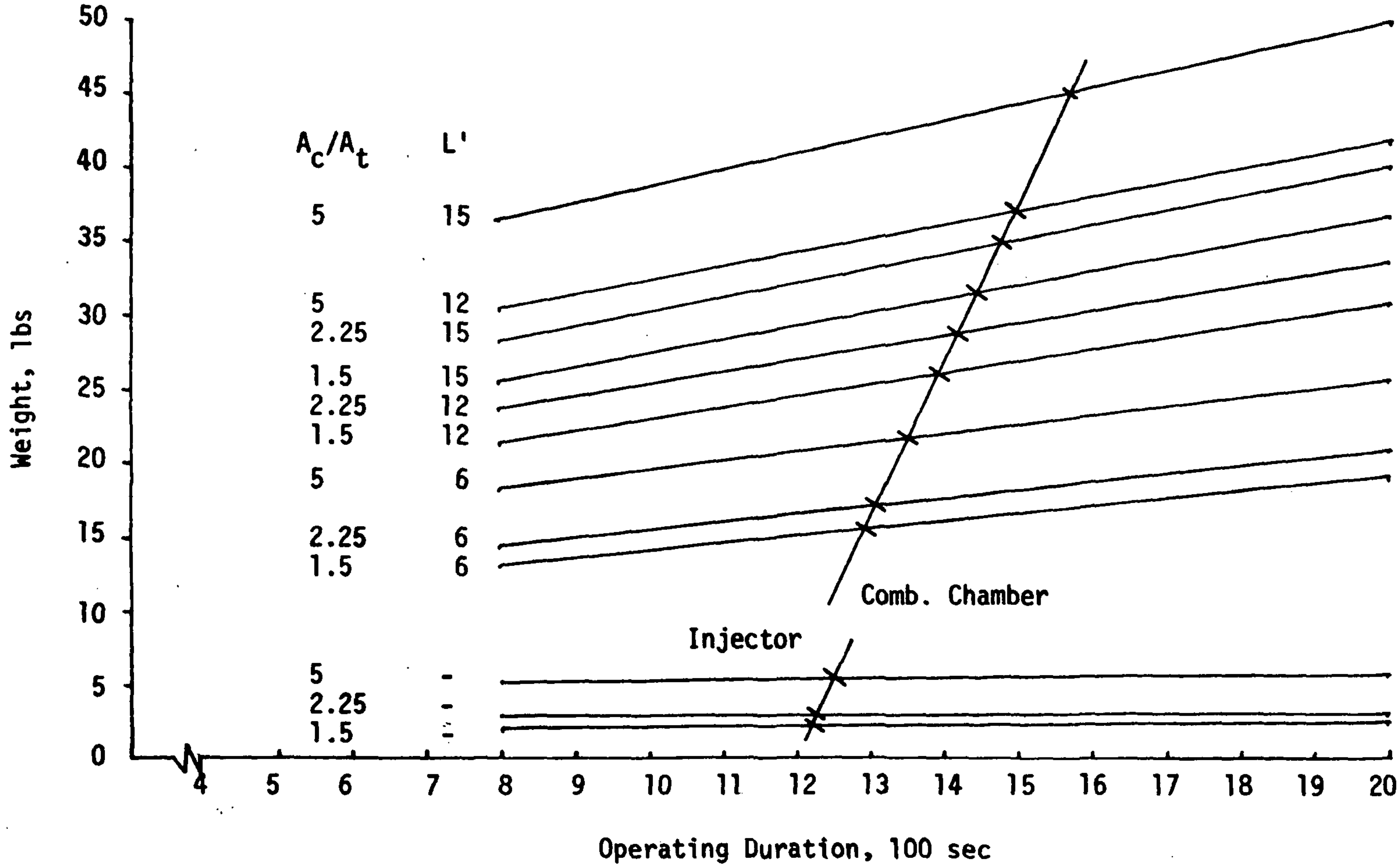


Figure 31. Injector and Chamber Weight versus Duration for Liquid-Liquid Engines at P_c = 120 psia

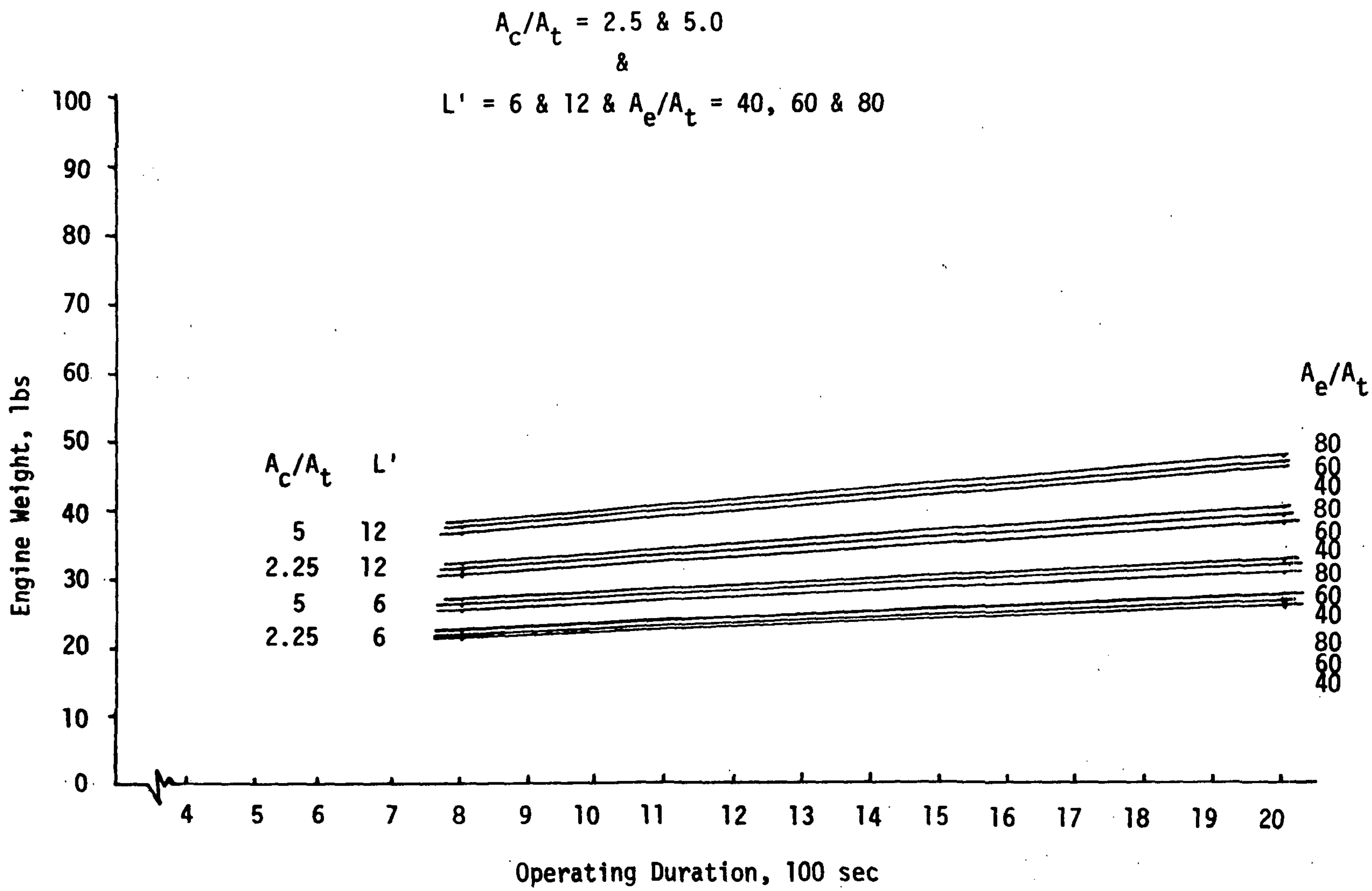


Figure 32. Weight versus Duration for Liquid-Liquid Engines at P_c = 200 psia

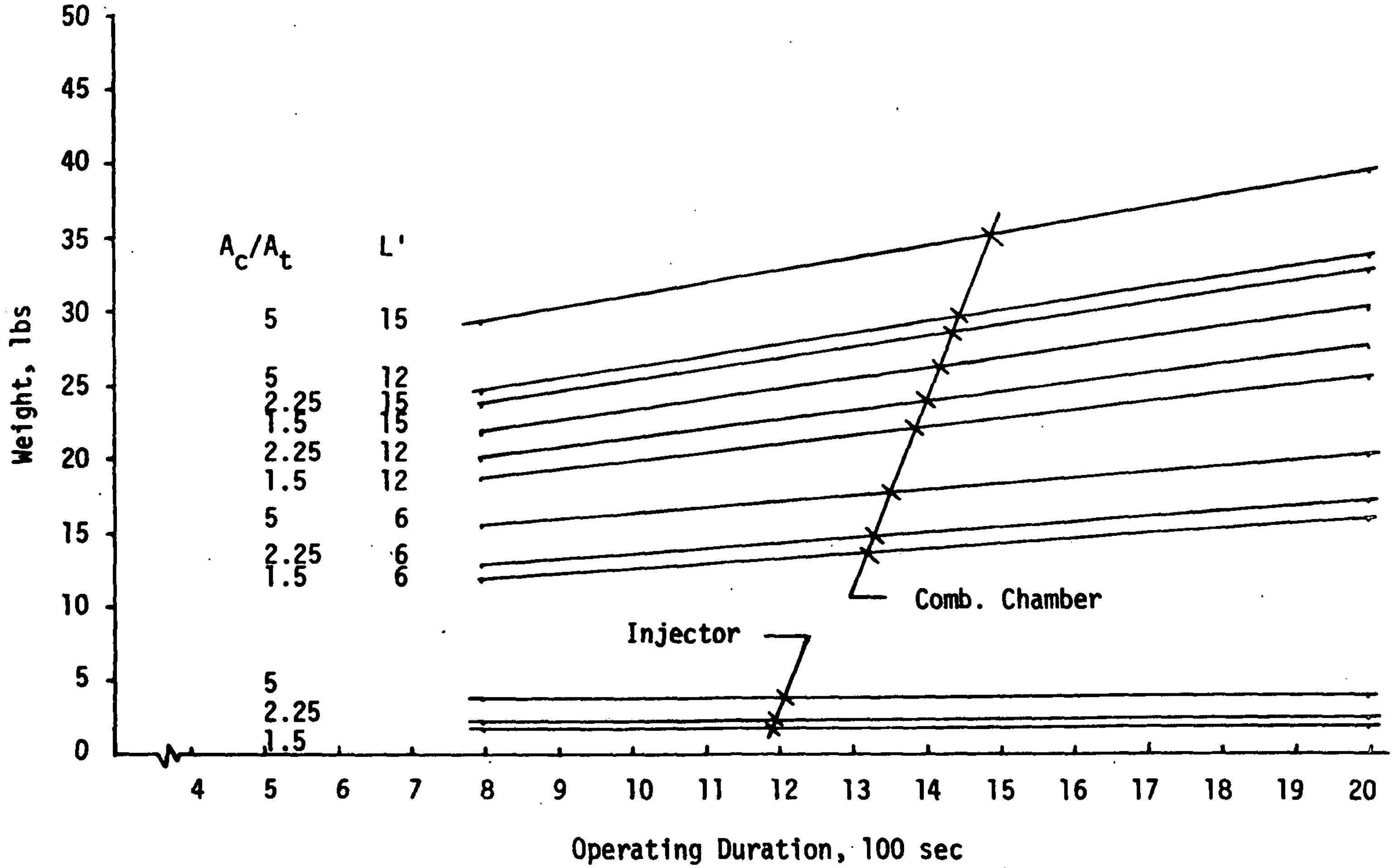


Figure 33. Injector and Chamber Weight versus Duration for Liquid-Liquid Engines at P_c = 200 psia

VI, A, Liquid-Liquid Engine Weight (cont.)

distance (L'), and area ratio are varied. These figures do not show engine weights for chambers having an L' in excess of 12.0 in. As there is a performance decrement as L' exceeds 12.0 in.

Figures 29, 31 and 33 present injector and thrust chamber weights for chamber pressures of 80, 120 and 200 psia as contraction ratio and L' are varied. Area ratio is not shown in these curves because the weights do not include the nozzle extension.

Table Set A of Appendix B presents the data used in the generation of Figures 25 through 33.

B. BIMODAL ENGINE WEIGHT

The calculation of engine weights for the bimodal design considered the effect of chamber pressure (P_c), contraction ratio (Ac/At), nozzle area ratio (Ae/At) and operating duration. The injector to throat distance (L') was held constant at 6.0 inches. This was due to the fact that the performance analysis showed that an energy release efficiency (ERE) of 99.0% could be attained in this distance and that further chamber length increases would not improve performance.

Figure 34 presents the weight of a 2000 second duration engine versus chamber pressure as contraction ratio and nozzle area ratio are varied. The contraction ratio variation has a substantial impact. This is due to the mean diameter of the relatively thick walled chamber changing as the contraction ratio varies.

Nozzle area ratio has a lesser effect on engine weight simply because the nozzle extension is very thin walled. The weight versus P_c curve for an area ratio 40, contraction ratio 2.50 engine is missing from Figure 34.

77

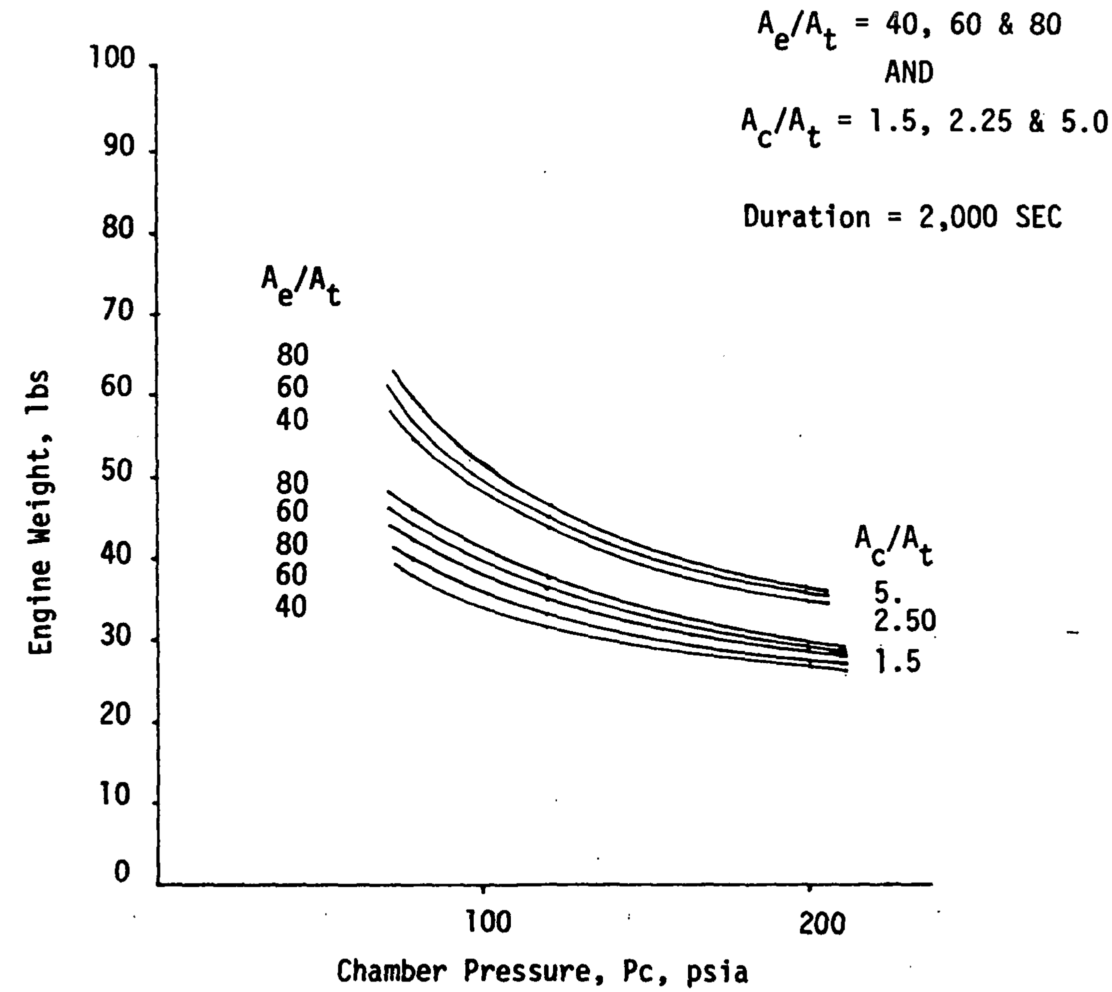


Figure 34. Weight versus P_c for Bimodal Engines with L' = 6 Inches

VI, B, Mimodal Engine Weight (cont.)

This is due to the curve being nearly coincident with that of the area ratio 80, contraction ratio 1.5, engine. Figure 35 is a cross plot of weight versus contraction ratio using the same data as shown in Figure 34.

Engine weight versus operating duration is presented in Figures 36, 38, and 40 for engines operating at chamber pressures of 80, 120 and 200 psia, respectively. Figures 37, 39 and 41 which back each of the previous figures provide the weights of the thrust chamber and injector. These curves do not show a nozzle area ratio parameter because the nozzle extension weights are not included. They do indicate, however, that the thrust chamber weights of the lower P_c engines are most sensitive to duration. In fact, it is only the radial displacement of the injector to chamber flange due to increasing chamber wall thickness that causes the injector weight to increase with operating duration.

The weight data used in the construction of Figures 34 through 41 is presented in Table Set B of Appendix B.

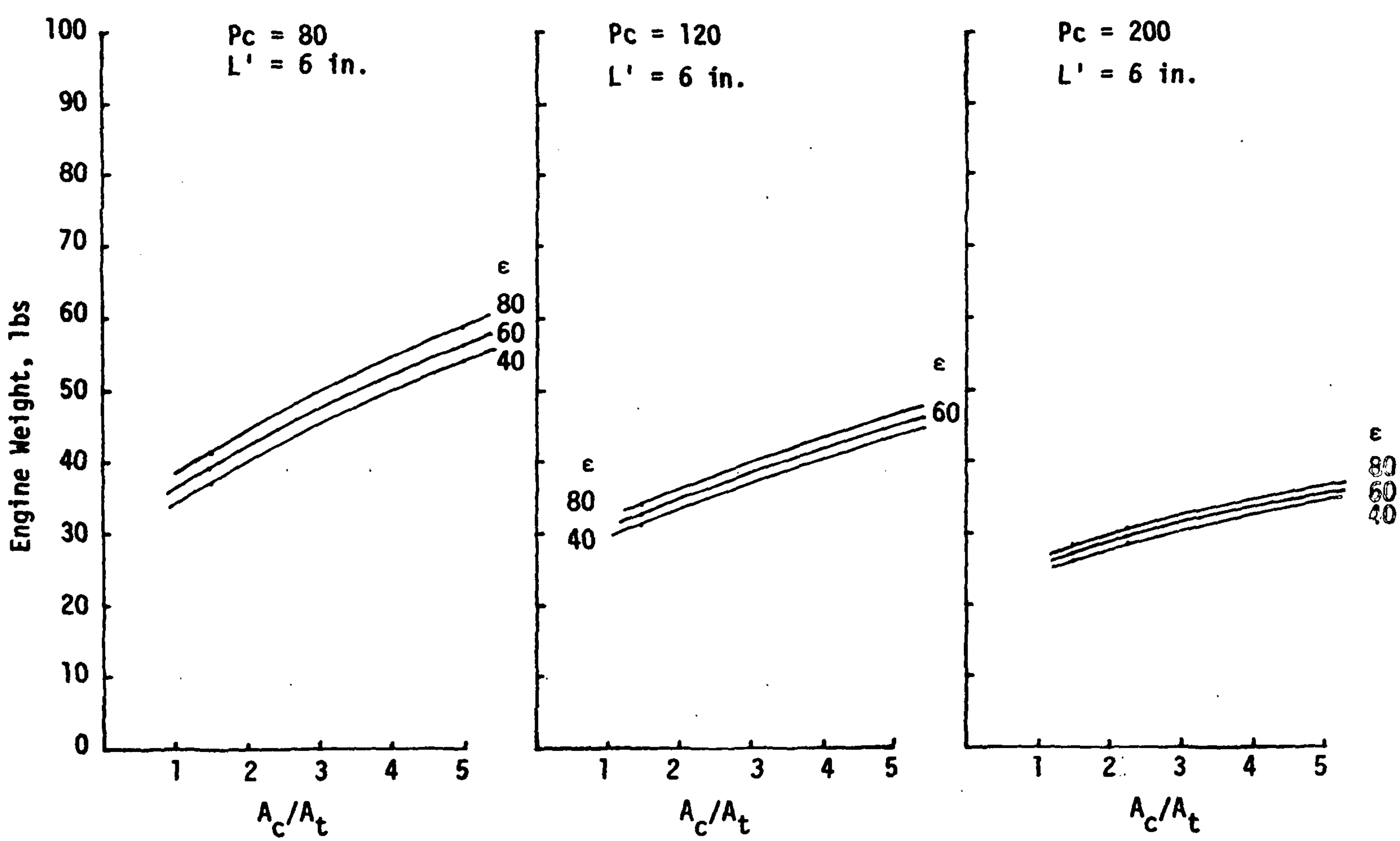


Figure 35. Weight versus Contraction Ratio for Bimodal Engines at P_c's of 80, 120 and 200 psia

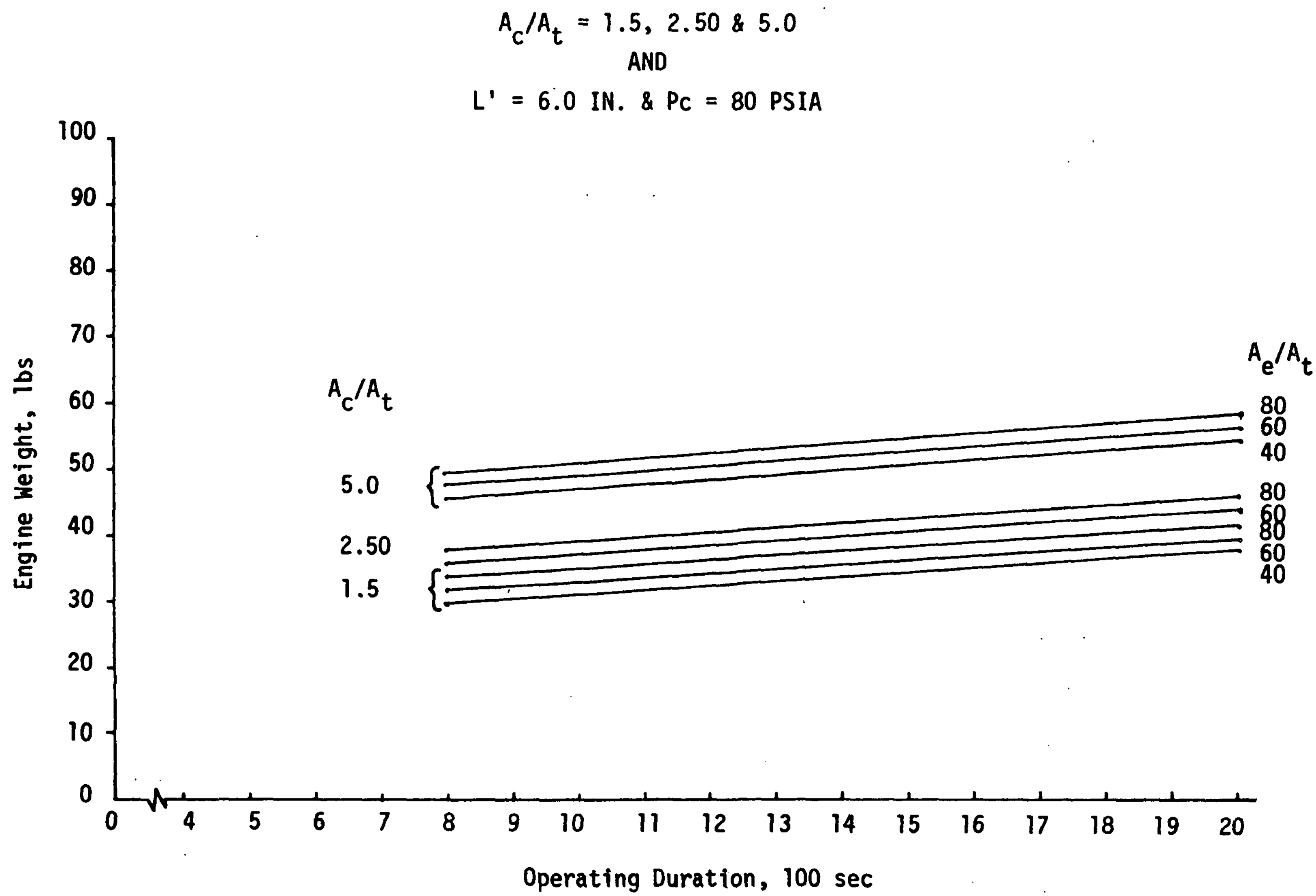


Figure 36. Weight versus Duration for Bimodal Engines at P_c = 80 psia

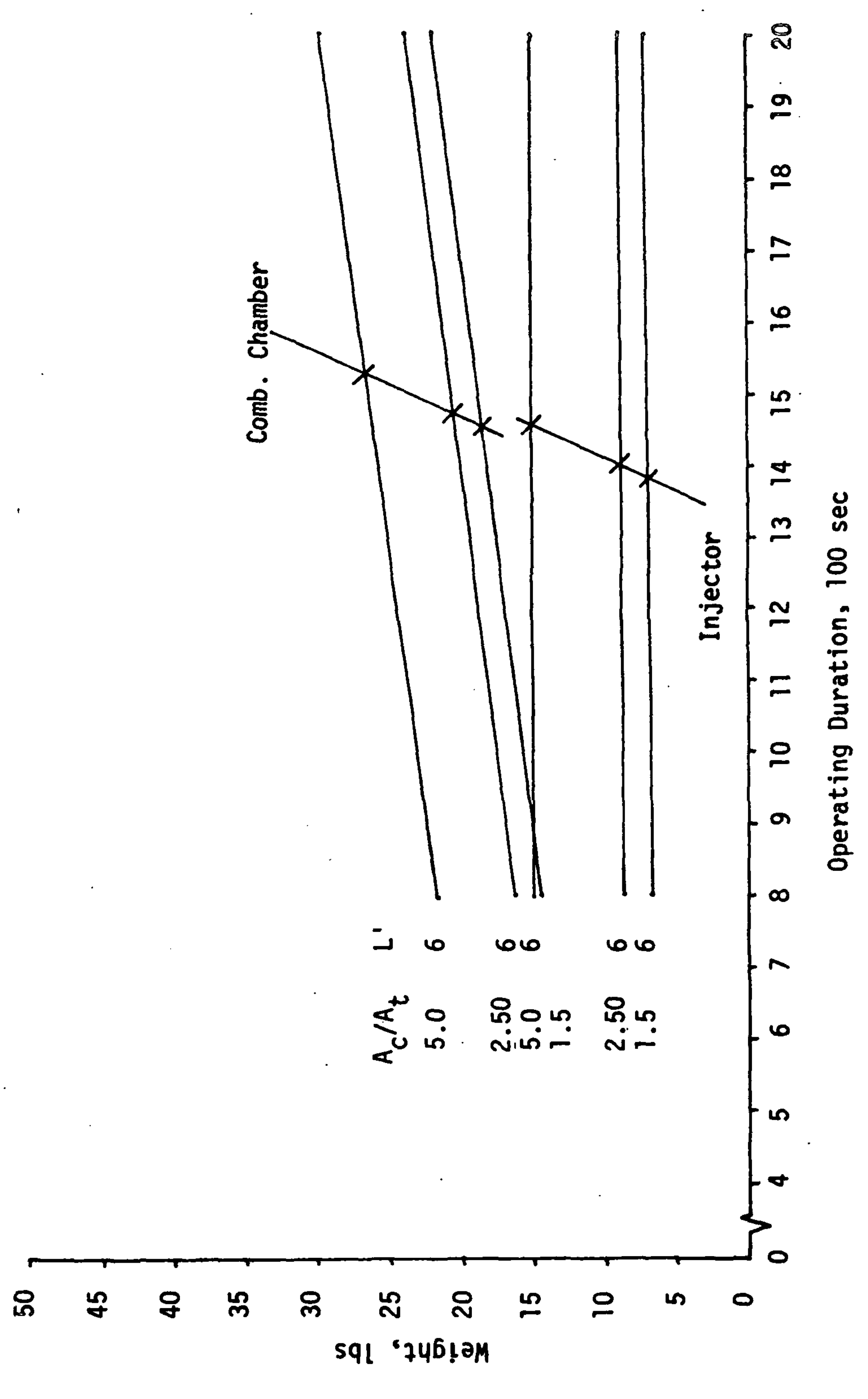


Figure 37. Injector and Chamber Weight versus Duration for Bimodal Engines at P_c = 80 psia

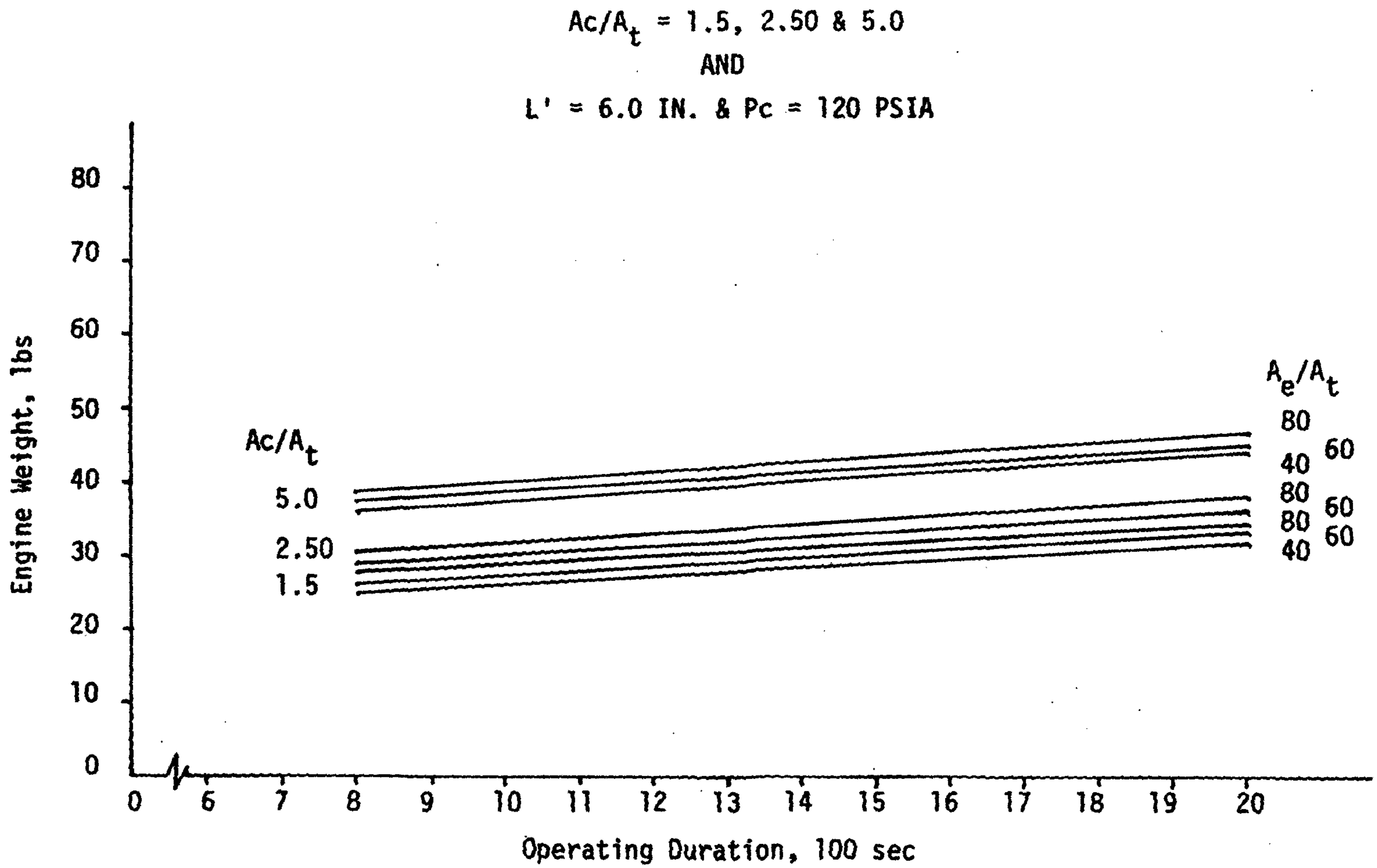


Figure 38. Weight versus Duration for Bimodal Engines at P_c = 120 psia

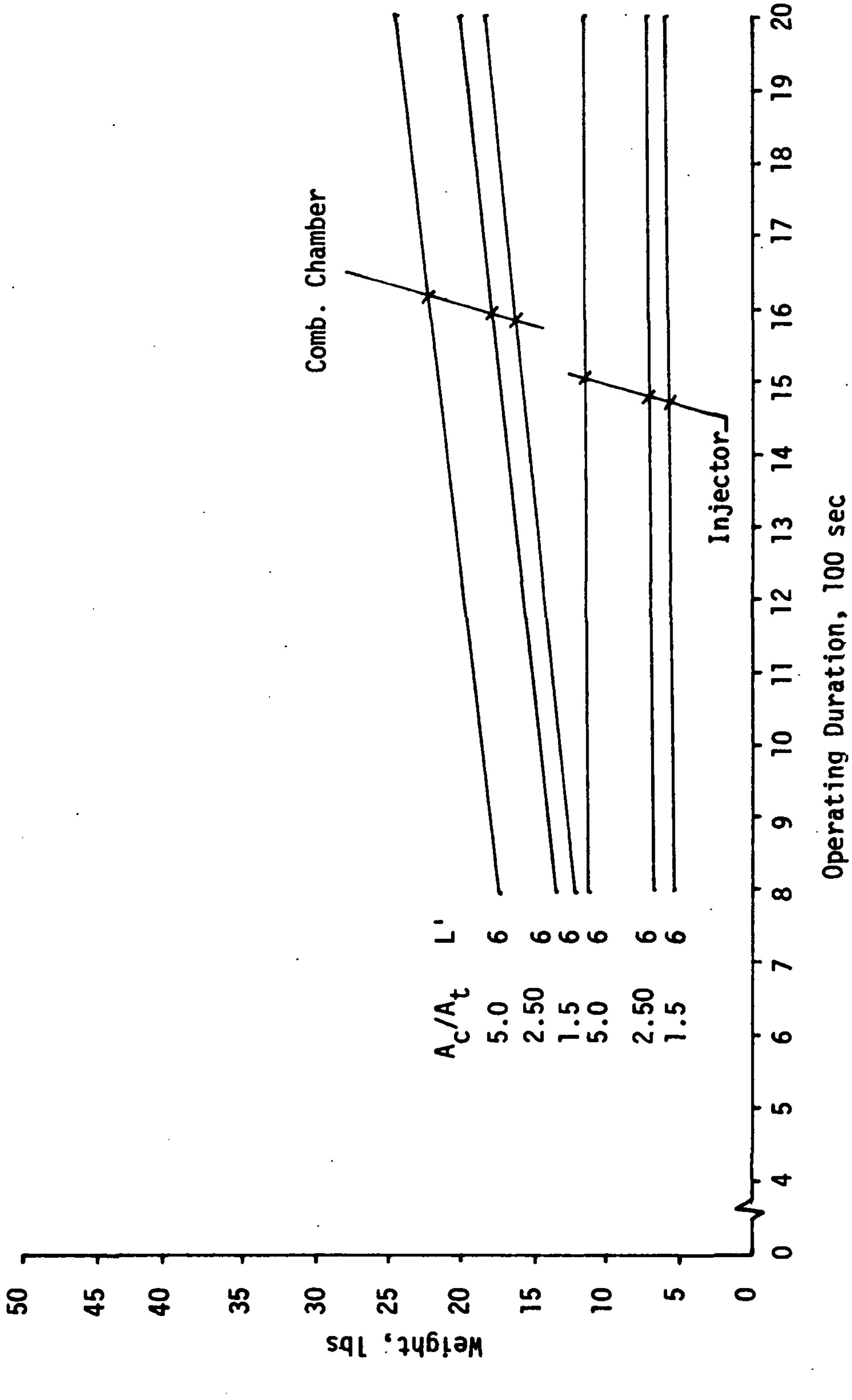


Figure 39. Injector and Chamber Weight versus Duration for Bimodal Engines at P_c = 120 psia

84

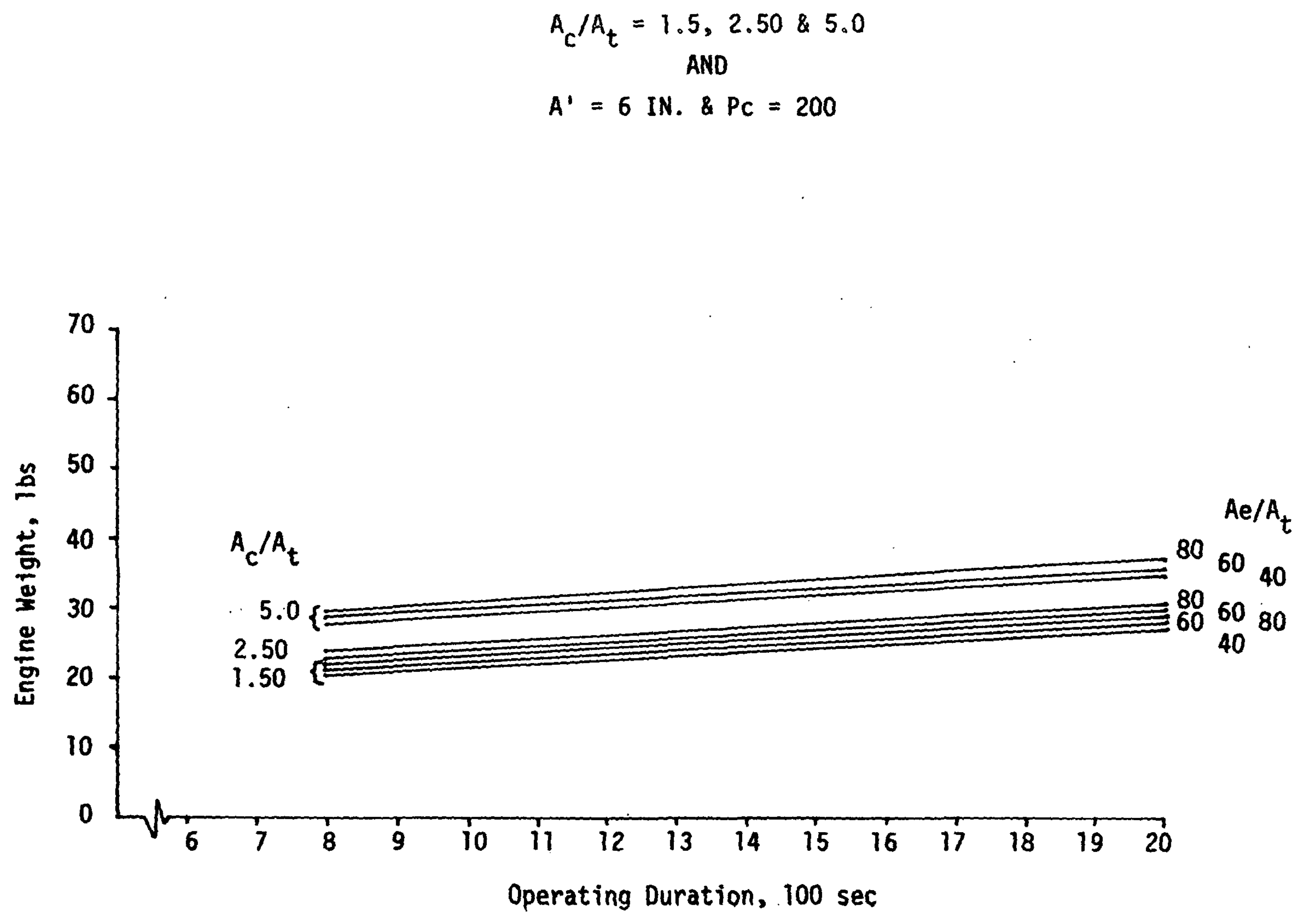


Figure 40. Weight versus Duration for Bimodal Engines at P_c = 200 psia

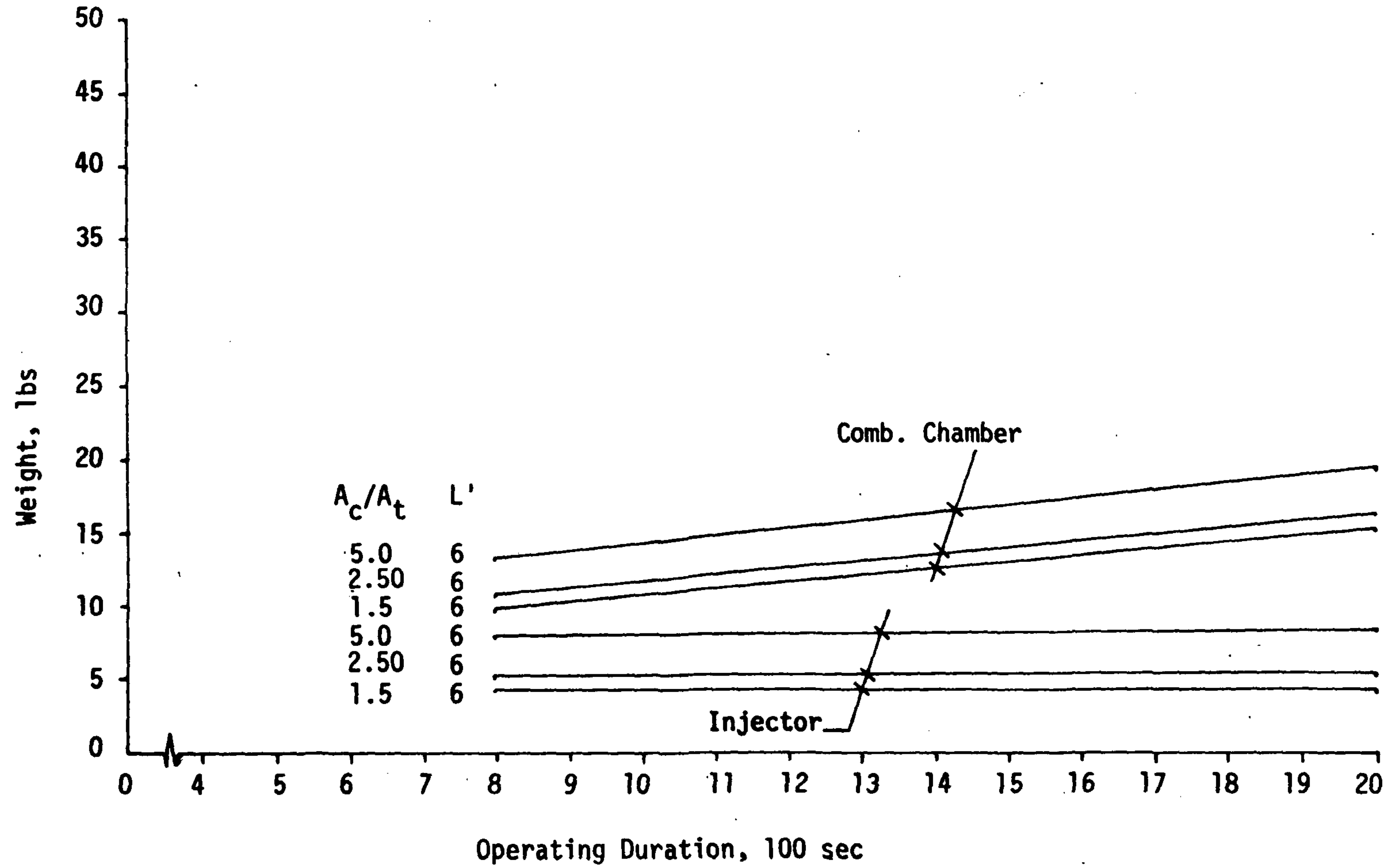


Figure 41. Injector and Chamber Weight versus Duration for Bimodal Engines at P_c = 200 psia

VII. DATA INTEGRATION

The performance and weight data presented in Sections V and VI were reviewed to insure an absence of anomalies with regard to either weight and performance and to identify trends which would allow optimization of the liquid-liquid and bimodal engines. It was found that the selection of the optimum bimodal engine was very straight forward due to the fact that the minimum L' (6.0 in.) engine has the highest performance. The liquid-liquid engine trade is more complex due to the influence of area ratio, L' and contraction ratio on both performance and weight. Performance values used in these studies were selected from the tabulated data of Appendix A. Each I_{sp} value used is the maximum at a given operating condition without consideration of maintaining a constant mixture ratio.

Figure 42 presents I_{sp} versus engine weight for the 2000 second, 2.5 contraction ratio bimodal engine as L', nozzle area ratio and P_c are varied. It can be seen that L' increases do not improve performance while increasing engine weight.

Bimodal engine performance versus engine length is presented in Figure 43. This data is for engines having contraction ratios of 1.5, 2.5 and 5.0. Contraction ratio does not affect the bimodal engine's performance.

The bimodal engine's weight and length are plotted in Figure 44. In this case the effect of contraction ratio is more evident. The smaller contraction ratio unit has a weight advantage of about three pounds.

The data used to generate Figures 42 through 44 is tabulated in Figure 45.

The examination of the liquid-liquid engine's length, performance and weight as P_c, L' and nozzle area ratio are varied requires more consideration of the effects of L' and contraction ratio. Figures 46, 47 and 48 present

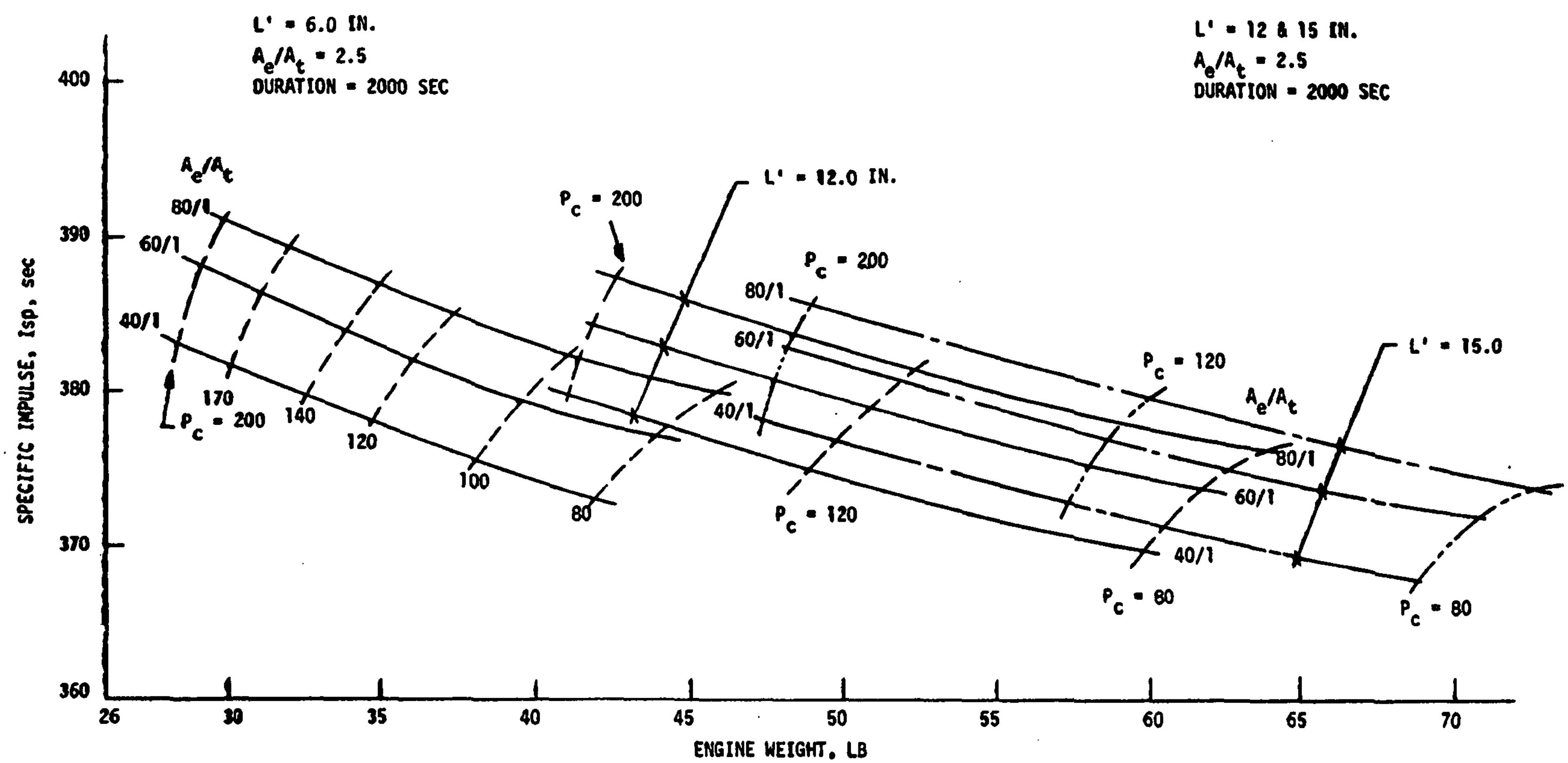


Figure 42. Bimodal Engine I_{sp} versus Weight

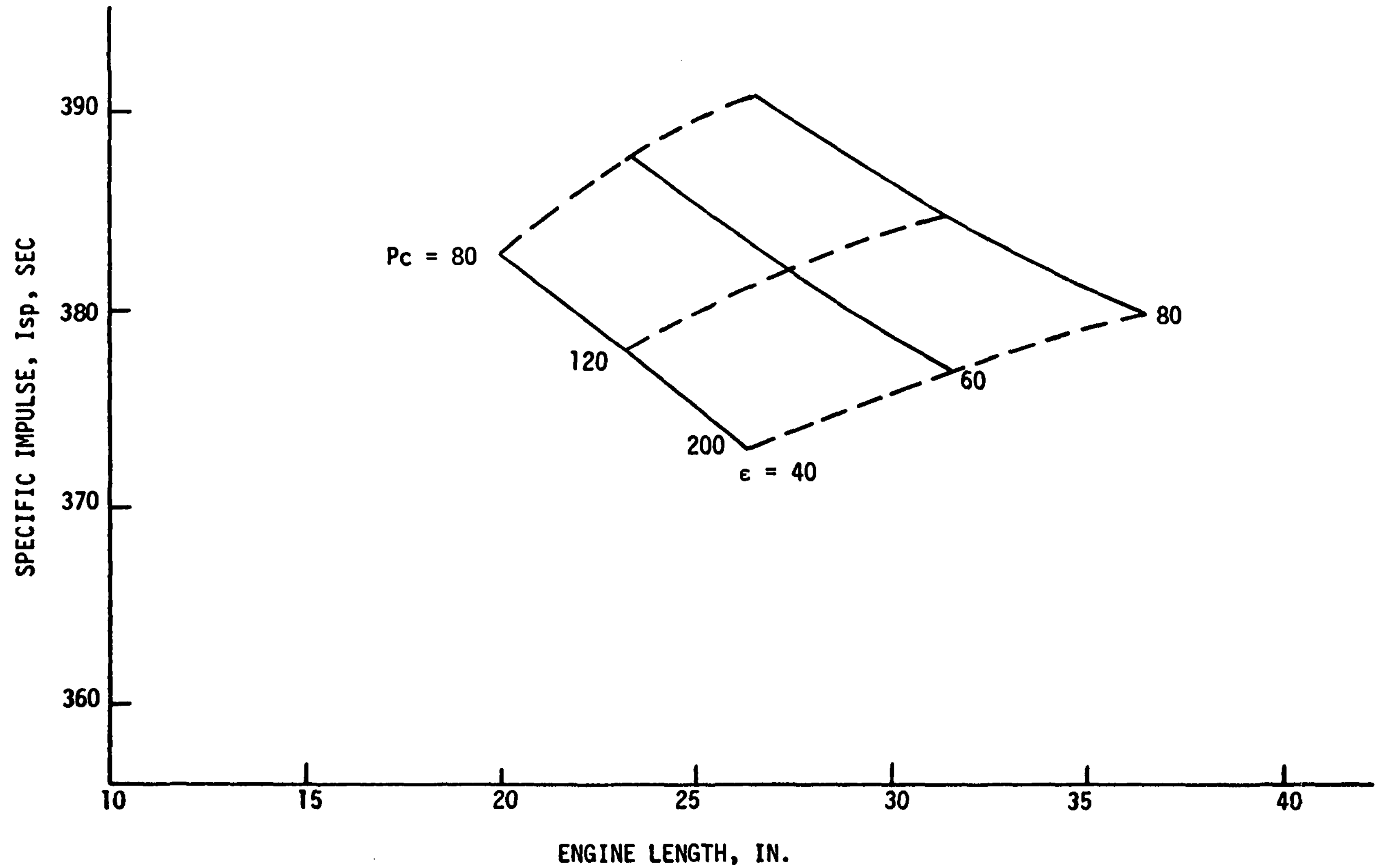


Figure 43. Bimodal Engine I_{sp} versus Engine Length as P_c and A_e/A_t are varied

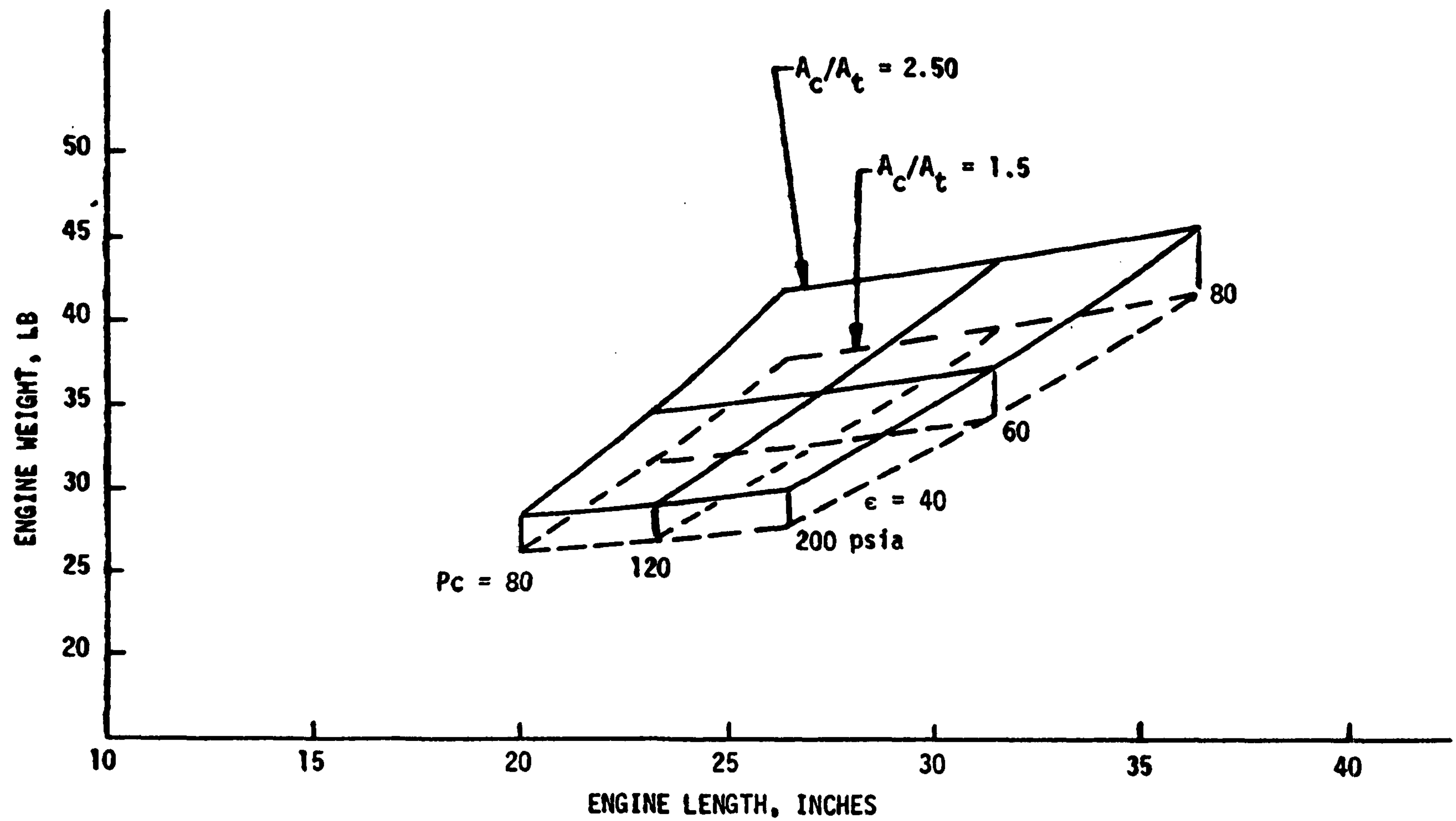


Figure 44. Bimodal Engine Weight versus Length for Engines Having Contraction ratios of 1.5 and 2.50

	AREA RATIO	L'	A_c/A_t	ENGINE LENGTH IN.	ENGINE WEIGHT LB	Isp SEC
Pc = 80	40	6	1.5	26.4	37.9	373
	60	6	1.5	31.6	39.8	378
	80	6	1.5	36.4	31.9	390
Pc = 120	40	6	1.5	23.2	31.6	378
	60	6	1.5	27.4	32.9	382
	80	6	1.5	31.4	34.3	385
Pc = 200	40	6	1.5	20.0	26.3	383
	60	6	1.5	23.3	27.1	388
	80	6	1.5	26.4	27.9	391
Pc = 80	40	6	2.5	26.4	41.9	373
	60	6	2.5	31.6	43.8	378
	80	6	2.5	36.4	45.9	390
Pc = 120	40	6	2.5	23.2	34.6	378
	60	6	2.5	27.4	35.9	382
	80	6	2.5	31.4	37.3	385
Pc = 200	40	6	2.5	20.0	28.3	383
	60	6	2.5	23.3	29.1	388
	80	6	2.5	26.4	29.9	391
Pc = 80	40	12(1)	2.5	32.4	59.8	370
	60	12	2.5	37.4	61.7	374
	80	12	2.5	42.4	63.8	376
Pc = 120	40	12	2.5	29.2	49.8	375
	60	12	2.5	33.4	51.1	379
	80	12	2.5	37.4	52.5	382
Pc = 200	40	12	2.5	26.0	41.1	380
	60	12	2.5	29.3	41.9	384
	80	12	2.5	32.4	42.7	387
Pc = 80	40	15(1)	2.5	35.4	68.8	368
	60	15	2.5	40.4	70.7	372
	80	15	2.5	45.4	72.8	374
Pc = 120	40	15	2.5	32.2	57.4	373
	60	15	2.5	36.4	48.7	377
	80	15	2.5	40.4	60.1	380
Pc = 200	40	15	2.5	29.4	47.4	378
	60	15	2.5	32.3	48.2	383
	80	15	2.5	35.3	49.0	386

(1) The bimodal engine does not obtain any performance advantage with increasing L' (combustion length).

Figure 45. Bimodal Engine Weight, Length and I_{sp} Summary

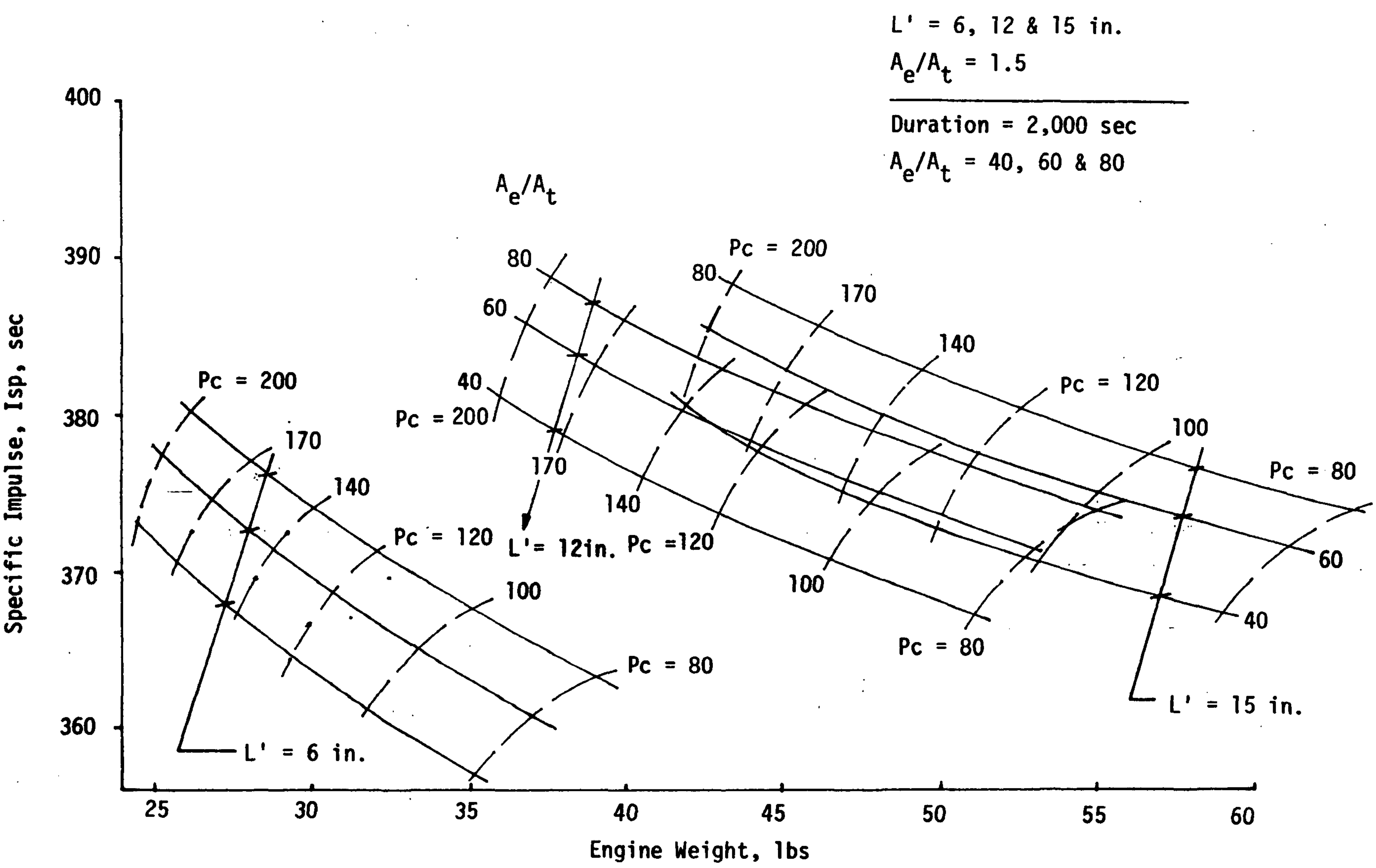


Figure 46. Liquid-Liquid Engine I_{sp} versus Weight for A_c/A_t = 1.5

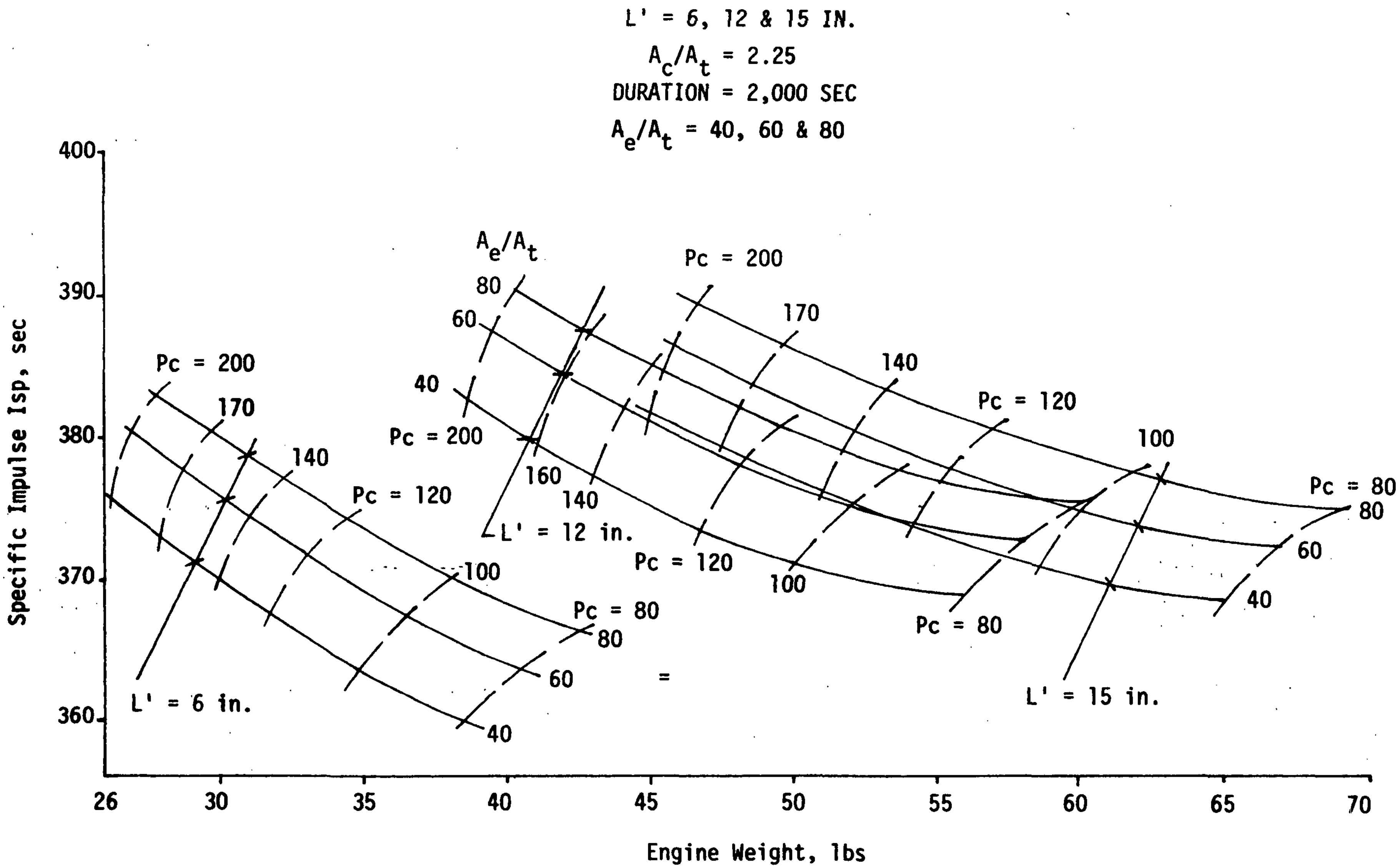


Figure 47. Liquid-Liquid Engine I_{sp} versus Weight for A_c/A_t = 2.25

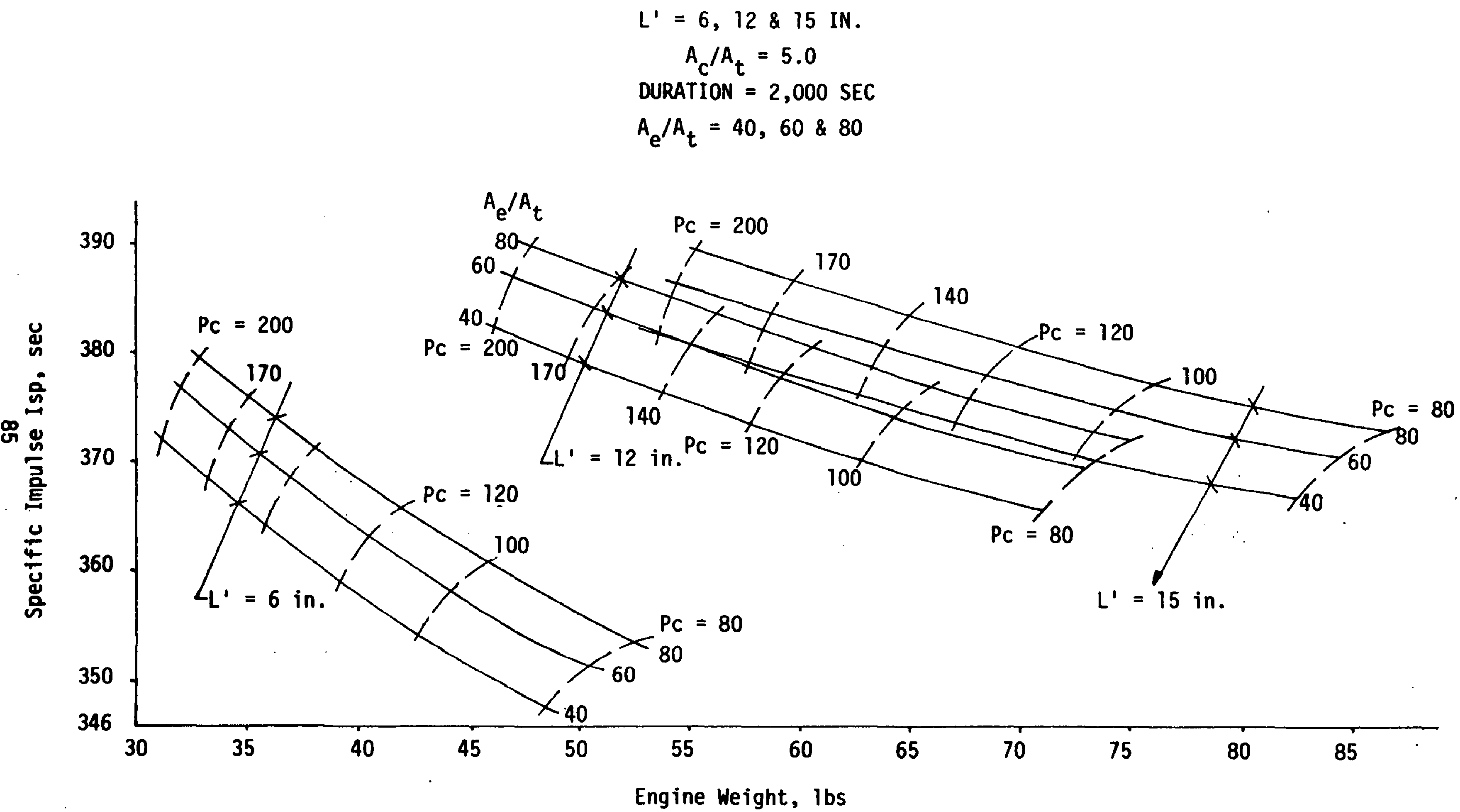


Figure 48. Liquid-Liquid Engine I_{sp} versus Weight for A_c/A_t = 5.0

VII, Data Integration (cont.)

performance versus weight for 2000 second duration, liquid-liquid engines having contraction ratios of 1.5, 2.25 and 5.0 respectively. It, can be seen that the 12.0 inch L', 2.25 contraction ratio unit is the highest performing.

Liquid-liquid engine performance versus length is presented in Figures 49, 50 and 51 for engines having contraction ratios of 1.5, 2.25 and 5.0 respectively. This data shows the contraction 2.25 and 5.0 units which have 12.0 in. L' and 15.0 in. L' to have virtually the same performance. The overlap of the 12 in. L' and 15 in. L' "boxes" indicate that a trade between L' and nozzle area ratio is possible for nearly the same I_{sp}.

This trade and its effect on engine weight is illustrated in Figures 52, 53 and 54 which present engine weight versus length for contraction ratios of 1.5, 2.25 and 5.0 respectively. It is evident from these figures that increasing L' adversely effects engine weight.

The use of Figures 49 through 51 to establish length-performance interaction and Figures 52 through 54 to identify length weight relationships will allow the selection of an optimum liquid-liquid engine operating point if a weight-I_{sp} correlation value is known.

Figure 55 tabulates the data used in the generation of Figures 46 through 54.

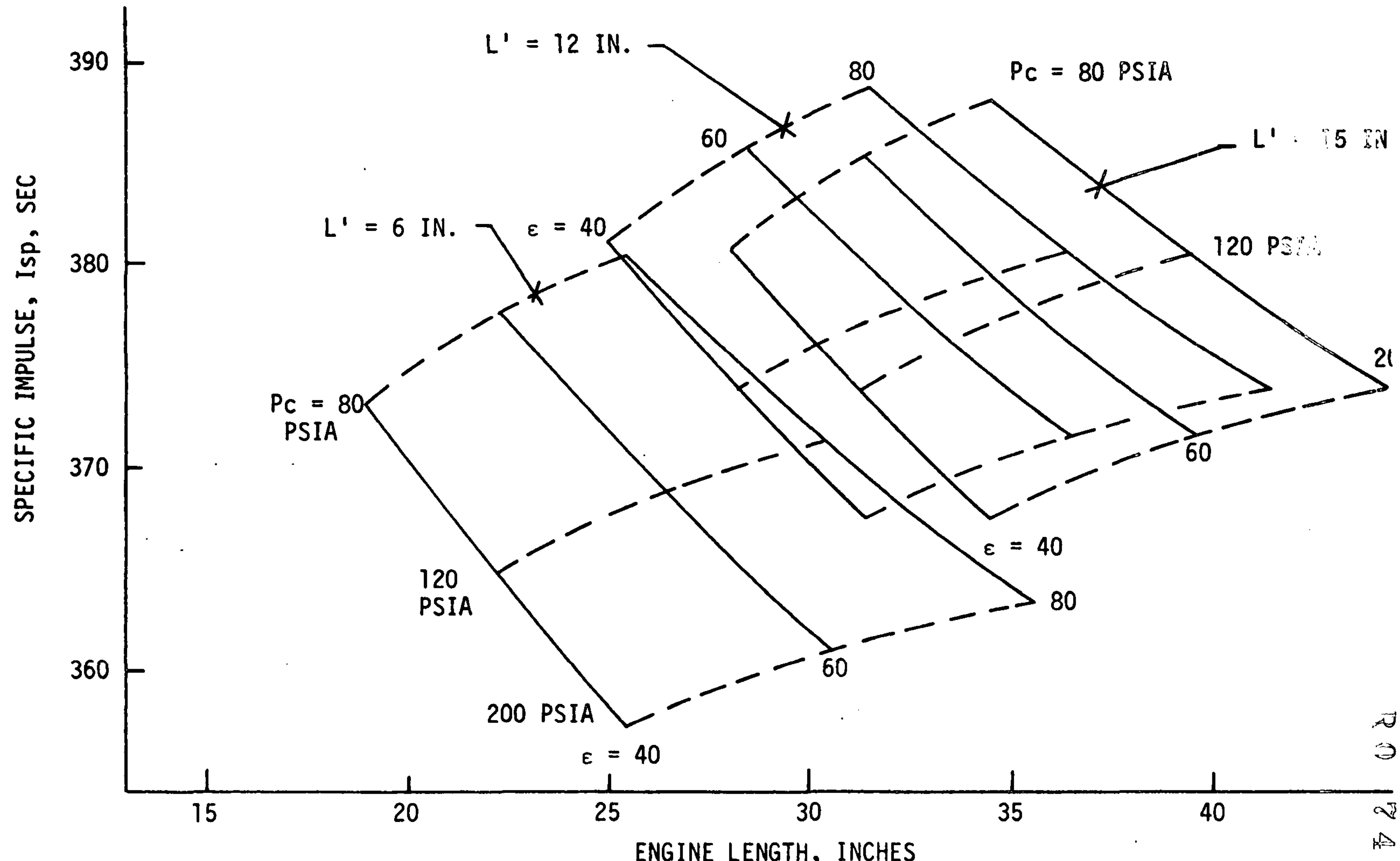


Figure 49. Liquid-Liquid Engine I_{sp} versus Engine Length for A_c/A_t = 1.5 and L' = 6, 12 and 15 Inches

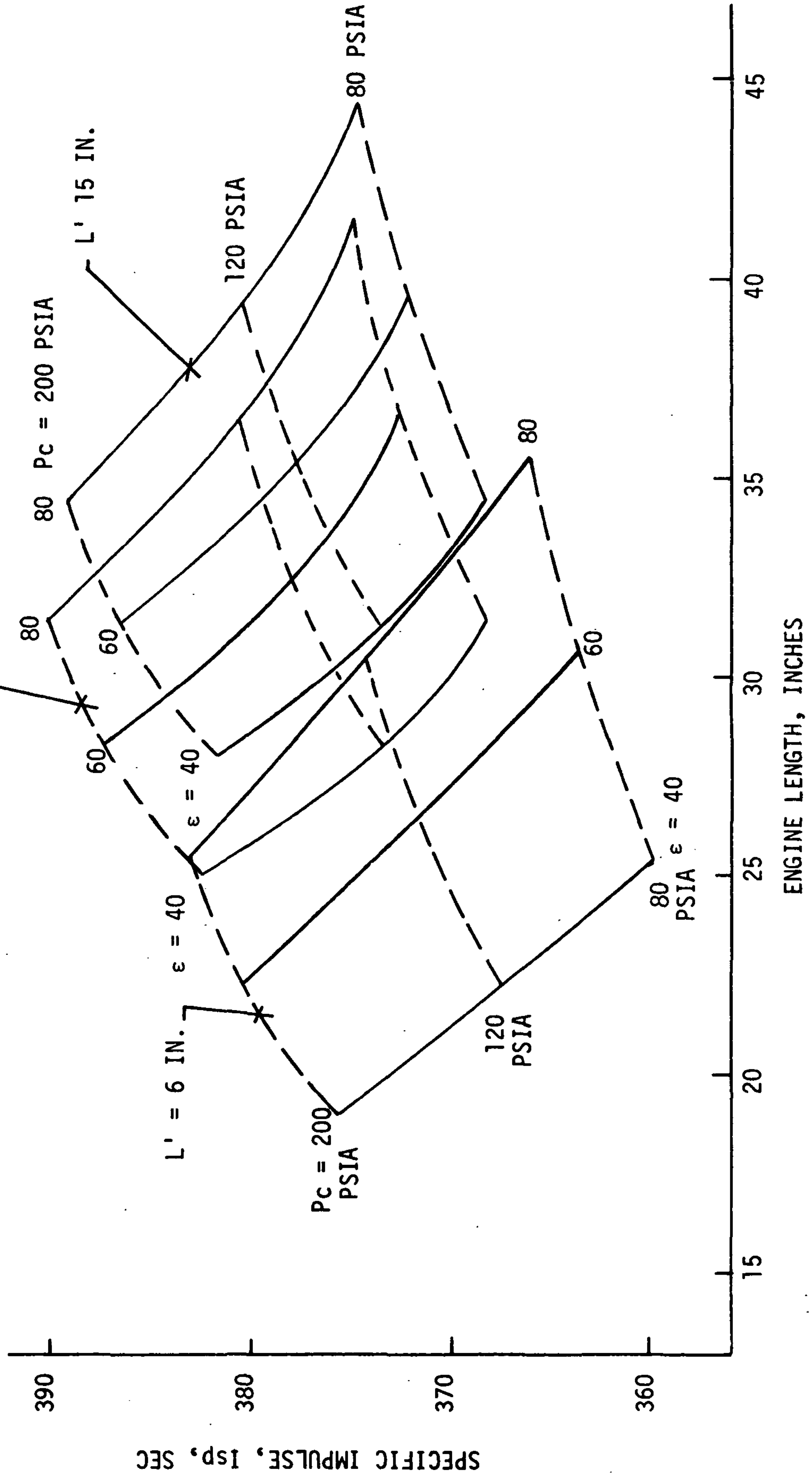


Figure 50. Liquid-Liquid Engine I_{sp} versus Engine Length for $A_c/A_t = 2.25$ and L' = 6, 12 and 15 Inches

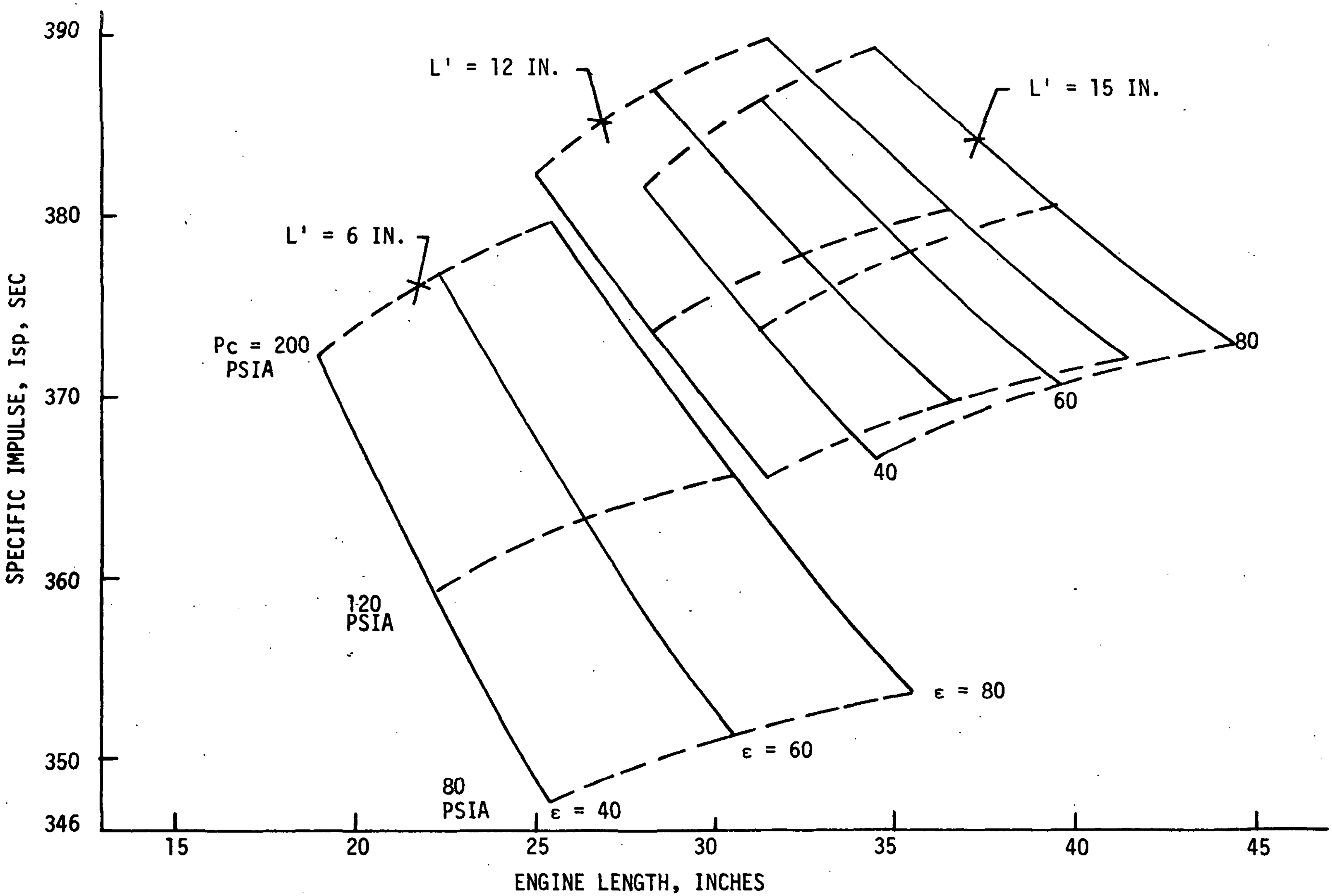


Figure 51. Liquid-Liquid Engine I_{sp} versus Engine Length for A_c/A_t = 5.0 and L' = 6, 12 and 15 Inches

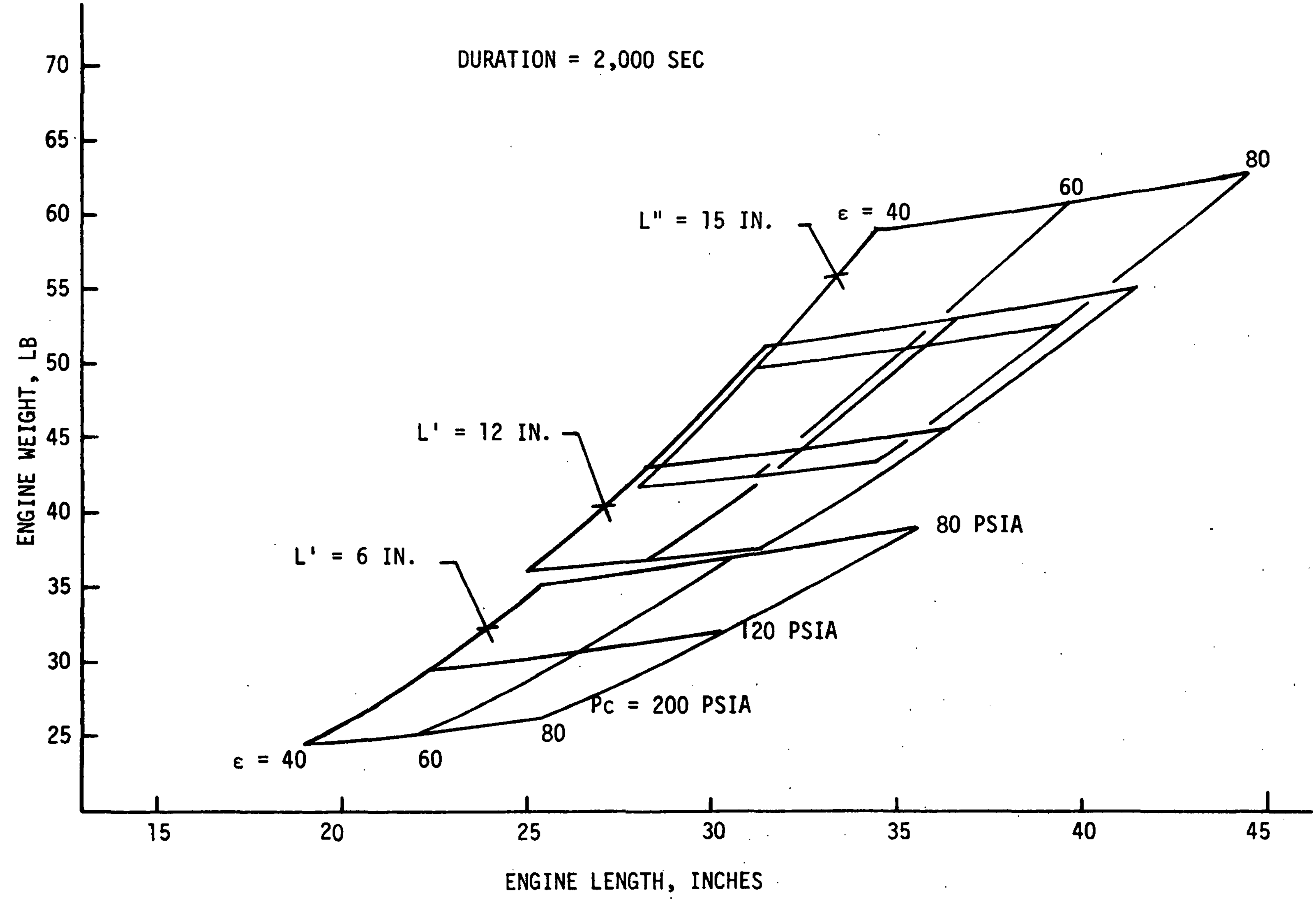


Figure 52. Liquid-Liquid Engine Weight versus Engine Length for $A_c/A_t = 1.5$

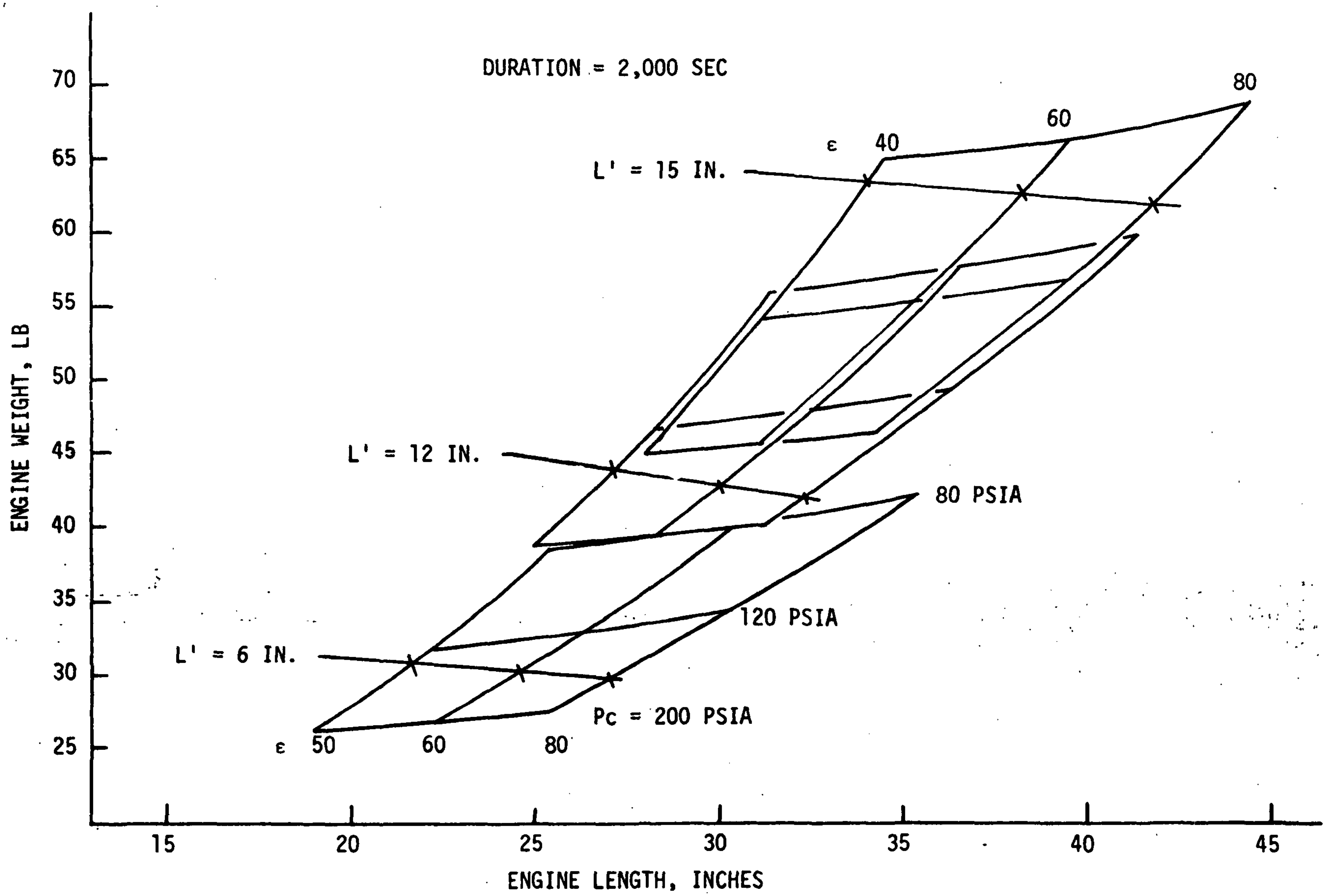


Figure 53. Liquid-Liquid Engine Weight versus Engine Length for $A_c/A_t = 2.25$

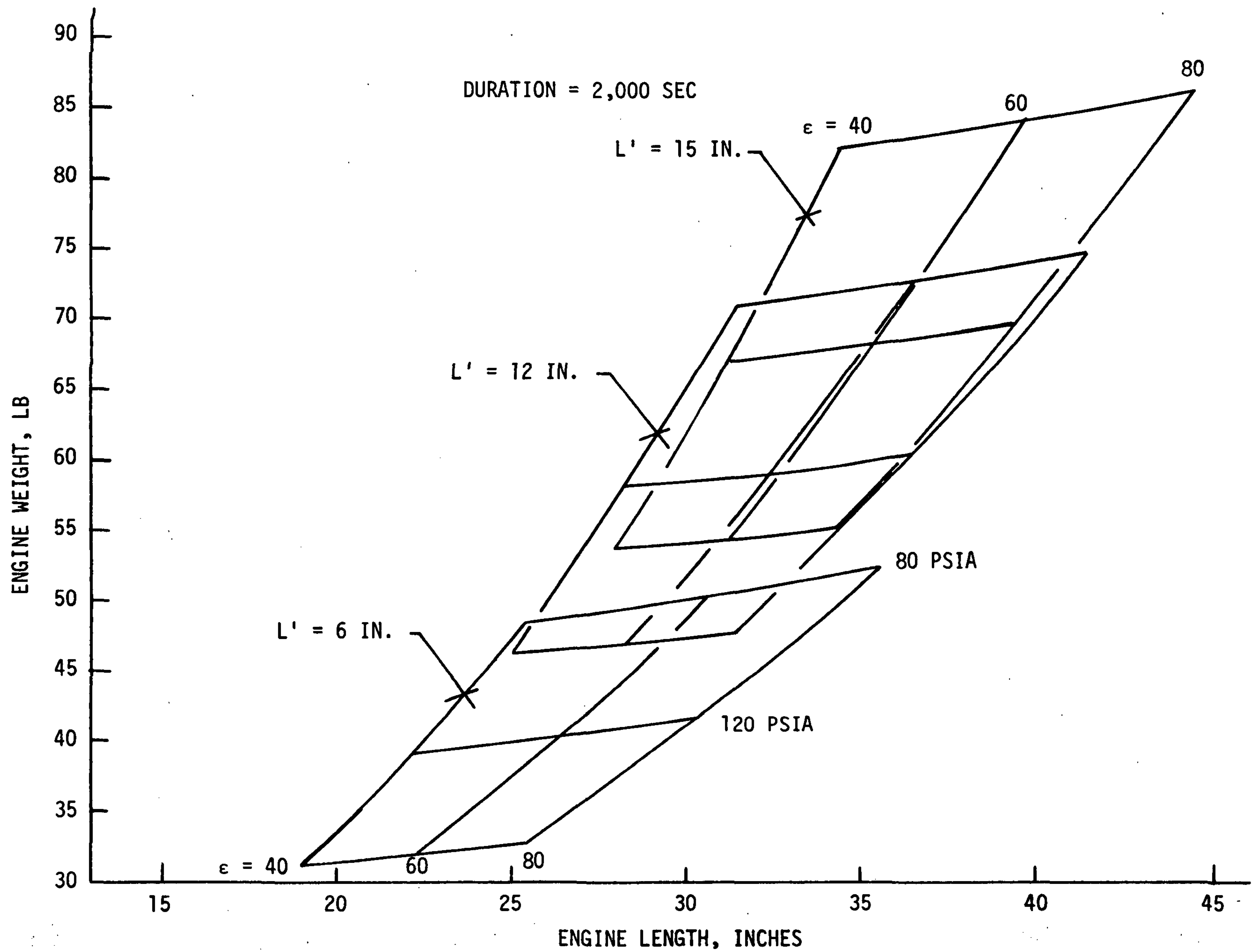


Figure 54. Liquid-Liquid Engine Weight versus Engine Length for $A_c/A_t = 5.0$

	AREA RATIO	L'	$A_c A_t$	ENGINE LENGTH IN.	ENGINE WEIGHT LB	Isp SEC
Pc = 80	40	6	1.5	25.4	35.1	357
	60	6	1.5	30.6	37.0	361
	80	6	1.5	35.5	39.1	363
Pc = 120	40	6	1.5	22.2	29.4	365
	60	6	1.5	26.4	30.7	369
	80	6	1.5	30.4	32.1	371
Pc = 120	40	6	1.5	19.0	24.5	373
	60	6	1.5	22.3	25.3	378
	80	6	1.5	25.4	26.1	380
Pc = 80	40	12	1.5	31.4	5.1	367
	60	12	1.5	36.5	53.0	371
	80	12	1.5	41.4	55.1	374
Pc = 120	40	12	1.5	28.2	43.0	374
	60	12	1.5	32.4	44.3	378
	80	12	1.5	36.4	45.7	381
Pc = 200	40	12	1.5	25.0	36.0	381
	60	12	1.5	28.3	36.8	386
	80	12	1.5	31.4	37.6	389
Pc = 80	40	15	1.5	34.4	49.0	368
	60	15	1.5	39.6	60.9	372
	80	15	1.5	44.4	63.0	374
Pc = 120	40	15	1.5	31.2	49.9	374
	60	15	1.5	35.4	51.2	370
	80	15	1.5	39.4	52.6	380
Pc = 200	40	15	1.5	28.0	41.8	381
	60	15	1.5	31.3	42.6	385
	80	15	1.5	34.4	43.4	388
Pc = 80	40	6	2.25	25.4	38.4	360
	60	6	2.25	30.6	40.3	364
	80	6	2.25	35.5	42.4	366
Pc = 120	40	6	2.25	22.2	31.7	368
	60	6	2.25	26.4	33.0	372
	80	6	2.25	30.4	34.4	374
Pc = 200	40	6	2.25	19.0	26.1	376
	60	6	2.25	22.3	26.9	380
	80	6	2.25	25.4	27.7	383

Figure 55. Liquid-Liquid Engine Weight, Length and I_{sp} Summary (Sheet 1 of 2)

102

	AREA RATIO	L'	$A_c A_t$	ENGINE LENGTH IN.	ENGINE WEIGHT LB	Isp SEC
Pc = 80	40	12	2.25	31.4	55.9	367
	60	12	2.25	36.5	57.8	373
	80	12	2.25	41.4	59.9	375
Pc = 120	40	12	2.25	28.2	46.7	373
	60	12	2.25	32.4	38.0	378
	80	12	2.25	36.4	49.4	381
Pc = 200	40	12	2.5	25.0	38.6	383
	60	12	2.5	28.3	39.4	387
	80	12	2.5	31.4	40.2	390
Pc = 80	40	15	2.5	34.4	64.9	368
	60	15	2.5	39.6	66.8	372
	80	15	2.5	44.4	689	375
Pc = 120	40	15	2.5	31.2	54.1	374
	60	15	2.5	35.4	55.4	378
	80	15	2.5	39.4	56.8	380
Pc = 200	40	15	2.5	28.0	44.9	382
	60	15	2.5	31.3	45.7	387
	80	15	2.5	34.4	46.5	389
Pc = 80	40	6	5.0	25.4	48.4	348
	60	6	5.0	30.6	50.3	351
	80	6	5.0	35.5	52.4	354
Pc = 120	40	6	5.0	22.2	39.1	359
	60	6	5.0	26.4	30.4	363
	80	6	5.0	30.4	41.8	366
Pc = 200	40	6	5.0	19.0	31.1	372
	60	6	5.0	22.3	31.9	377
	80	6	5.0	25.4	32.7	380
Pc = 80	40	12	5.0	31.4	70.9	366
	60	12	5.0	36.5	72.8	370
	80	12	5.0	41.4	74.9	372
Pc = 120	40	12	5.0	28.2	57.7	374
	60	12	5.0	32.4	59.0	378
	80	12	5.0	36.4	60.4	380
Pc = 200	40	12	5.0	25.0	46.1	382
	60	12	5.0	28.3	46.9	387
	80	12	5.0	31.4	47.7	390
Pc = 80	40	15	5.0	34.4	82.3	367
	60	15	5.0	39.6	84.2	371
	80	15	5.0	44.4	86.3	373
Pc = 120	40	15	5.0	31.2	67.0	374
	60	15	5.0	35.4	68.3	378
	80	15	5.0	39.4	69.7	381

Figure 55. Liquid-Liquid Engine Weight, Length and I_{sp} Summary (Sheet 2 of 2)

VIII. SYSTEMS EVALUATION

The comparison of the bimodal and liquid-liquid engines included an evaluation of their operating characteristics with regard to propellant feed systems and mission applicability as well as an assessment of engine differences as they affect the thermal design of a spacecraft.

A. ENGINE OPERATING CHARACTERISTICS AND PROPELLANT FEED SYSTEMS

Planetary probe spacecraft which have the greatest need for high performance, low bulk density propulsion systems, such as obtained using fluorine/hydrazine propellants, have requirements which are significantly different than those of earth orbiting systems. These are due to (1) long durations in transit prior to a high ΔV orbit insertion firings (the transfer phase on a flight to Jupiter is 756 days), (2) low accelerations due to the spacecraft's deployment of antennae and solar panels, and (3) low ΔV mid-course corrections which are widely spaced in time.

The design of a fluorine-hydrazine propulsion system for a planetary spacecraft is influenced by a variety of parameters. Some, such as spacecraft thermal design, related to the propellant selection alone, others such as expulsion system design and engine valving, are influenced by the engine concept selection. The following discussion is focused on the influence of engine concept.

Long-lived flight-weight fluorine valves and long-lived fluorine positive displacement propulsion systems have yet to be demonstrated. As a result, propulsion system designs frequently avoid the dependence upon these components. The propulsion system schematic shown in Figure 56[1] illustrates the use of normally-open and normally-closed squib actuated valves to accomplish

(1) Reference Report No. 14051-6009-RO-00, titled: Space Storable Propellant Module Thermal Control Technology, Summary Report, Volume II F_2/N_2H_4 Propulsion Module, dated 15 March 1971, by TRS Systems Group.

104

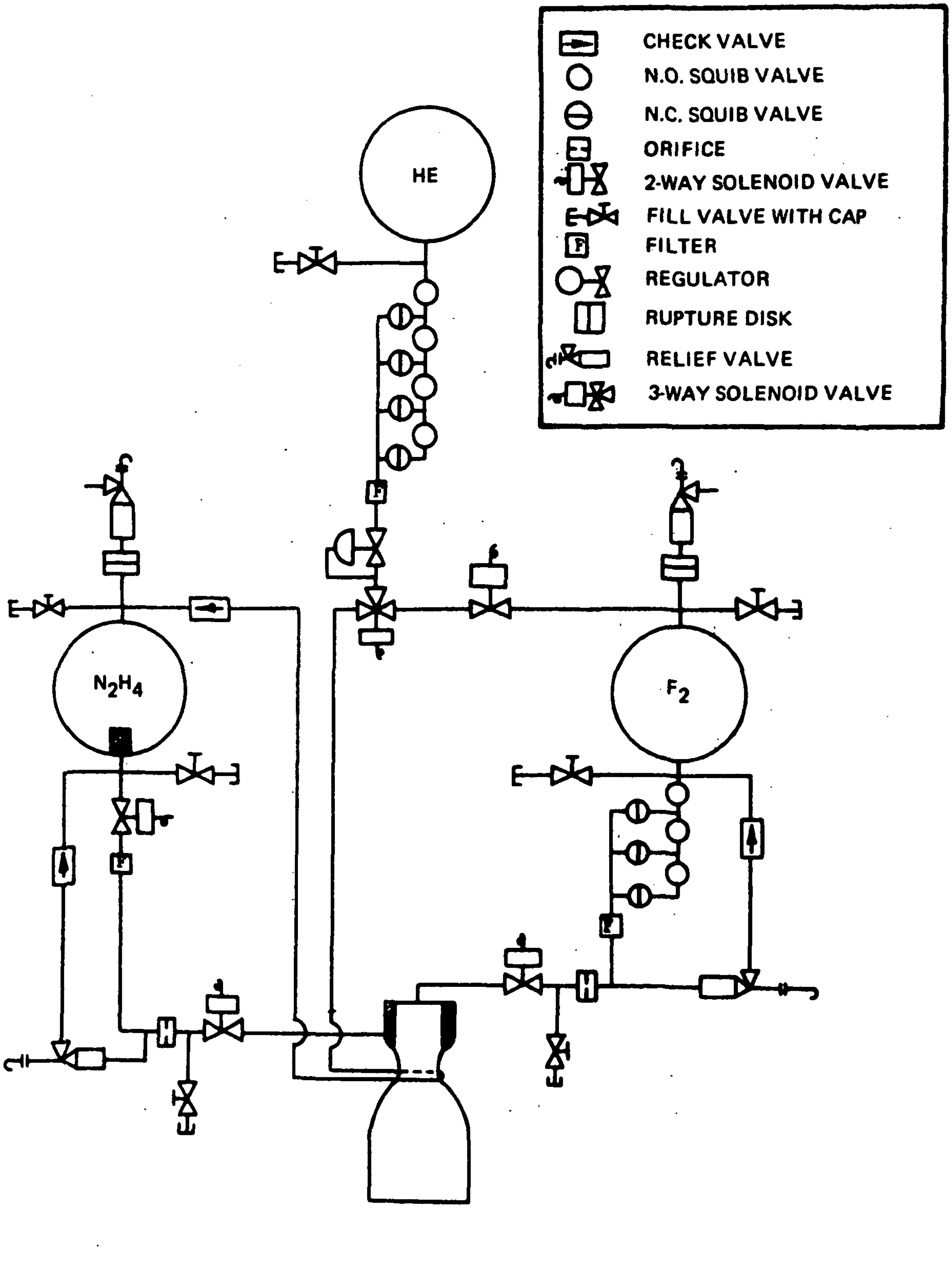


Figure 56. Schematic Diagram of F_2/N_2H_4 Spacecraft Propulsion System

105

three starts of a fluorine-hydrazine engine. As the fuel valve is solenoid actuated and can be operated without a limit on the quantity of actuations, the propellant system shown is best suited to a bimodal engine.

Using the system shown, the bimodal engine can provide an unlimited quantity of mid-course correction firings without a requirement for added squib actuated oxidizer valves or a need for a more sophisticated oxidizer valve. In addition, the bimodal engine operates at reduced thrust in the monopropellant mode limiting spacecraft acceleration loads and enhancing guidance C.G. acquisition. The addition of a fuel throttling valve to the feed system (Ref. Figure 56) of a 600 lbF thrust (bipropellant operation) bimodal engine would allow monopropellant mode thrust to be varied from about 25 to 150 lbF.

Zero gravity propellant acquisition from the fuel tank could be assured by either the use of a positive expulsion diaphram or screen tank liner. The former has been used on the hydrazine systems of communication satellites with life capabilities approaching ten years. Because the bimodal engine starts and shuts down with a fuel lead and override whose duration is not limited, the fuel lead (mono-mode operation) could be utilized to apply a positive "g" to the spacecraft to settle the oxidizer in its tank avoiding the requirement for a fluorine positive expulsion system. The liquid-liquid engine would require separate ullage rockets for this function.

B. ENGINE SPACECRAFT THERMAL INTERACTION

The design of the fluorine-hydrazine propulsion system is complicated by the hydrazine's relatively high freezing temperature coupled with the fluorine's need to be isolated from heat input. The rocket engine interacts with the spacecraft due to the need to (1) prevent the fuel from freezing or encountering temperatures high enough to result in fuel decomposition (detonation), and (2) protect the spacecraft from unanticipated heat input from the engine due to heat soak and/or radiation.

The bimodal engine has three thermal constraints. The fuel and fuel circuit hardware must be sufficiently warm at start that the fuel does not freeze in either the valve or hydrazine reactor injector. Secondly, the fuel circuit components must remain at a temperature below that which could cause the autodetonation of hydrazine. Thirdly, oxidizer heating must be avoided to preclude oxidizer boiling and injector vapor lock.

The liquid-liquid engine is less sensitive to propellant temperatures due to the absence of a catalyst bed and the elimination of the high temperature gaseous fuel. Hence, it can tolerate slightly lower fuel and slightly higher oxidizer temperatures. The fuel autodetonation problem is essentially the same as for the bimodal engine although design differences will result in unlike hydrazine circuit surface area to flow velocity ratios which in turn influence detonation temperature thresholds.

The preferred operating limits for each engine are summarized below.

	Bimodal	Liquid-Liquid
Minimum fuel valve temperature	40°F	36°F
Minimum hardware temperature	200°F[1] (catalyst)	40°F
Maximum fuel circuit temperature	350°F	350°F
Maximum oxidizer inlet temperature	-280°F	-260°F

[1] Preferred for maximum response and increased catalyst life. ALRC test data shows acceptable starts at fuel and hardware temperatures of 38°F.

VIII, B, Engine Spacecraft Thermal Interaction (cont.)

The calculated heat capacitances of the two engines (based on a C_p of 0.35 Btu/lb and temperature of 2500°F) at the conclusion of 2000 sec duration firings are 17,500 and 26,250 Btu for the bimodal and liquid-liquid units, respectively. Following shutdown, this heat is lost by radiation as well as conduction to adjacent components and structure. The higher capacitance of the liquid-liquid thrust chamber is due to its added length and mass. In the absence of a defined system configuration and engine installation heat transfer model, the capacitance values simply indicate that thermal isolation of the liquid-liquid engine will be more difficult.

APPENDIX A

PERFORMANCE EVALUATION DATA

APPENDIX A

FIGURE SET A

LIQUID-LIQUID ENGINE SPECIFIC IMPULSE VERSUS MIXTURE RATIO

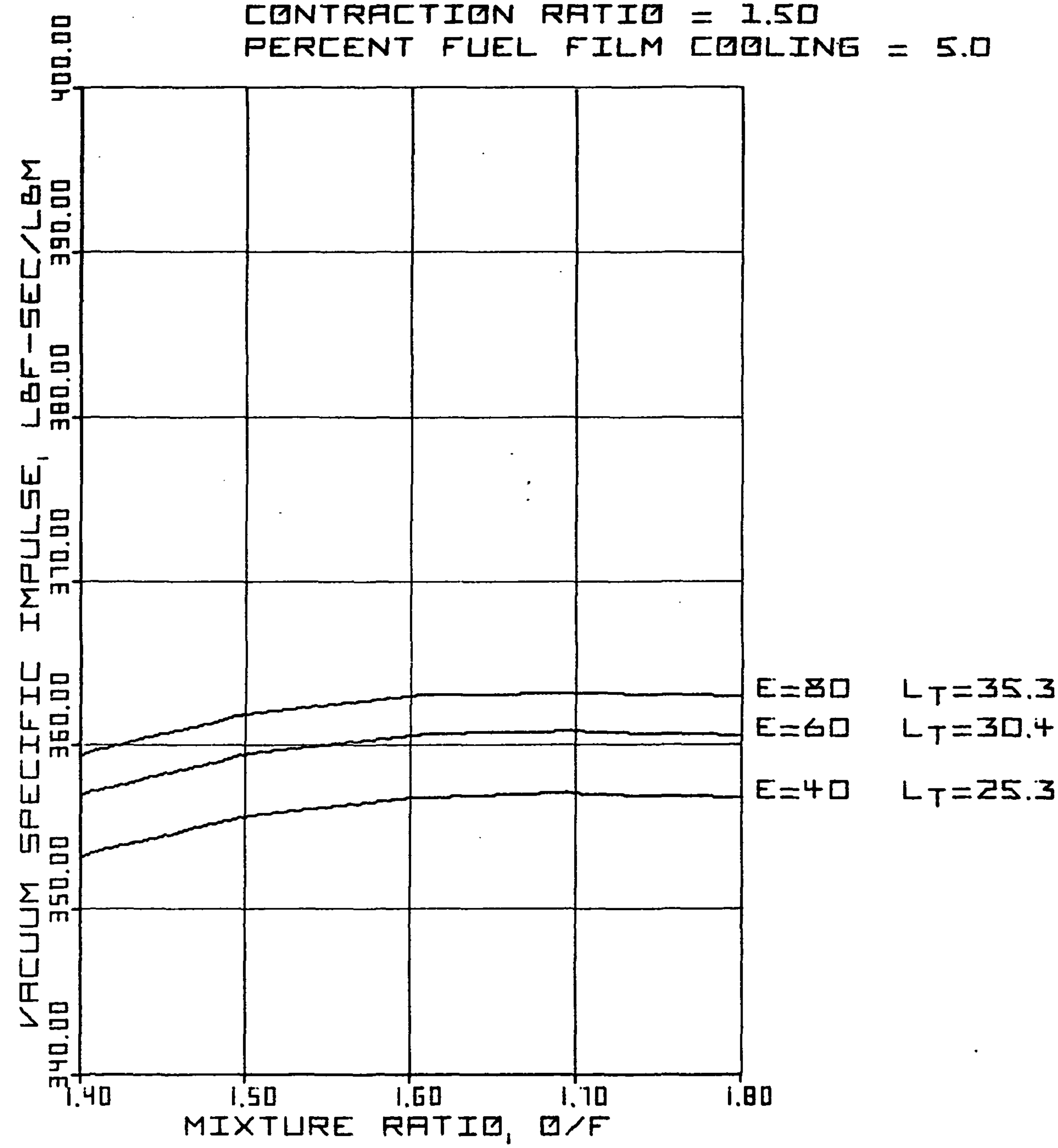
NOMENCLATURE LIST

THRUST	N (LBF)	ENGINE THRUST
PC	N/SQ.M (PSIA)	CHAMBER PRESSURE
O/F		MIXTURE RATIO
%FFC	% (%)	% FUEL FILM COOLING
EPS		AREA RATIO
CR		CONTRACTION RATIO
LPRIME	M (IN)	CHAMBER LENGTH
LNOZ	M (IN)	NOZZLE LENGTH
LENG	M (IN)	ENGINE LENGTH
%BELL		NOZZLE LENGTH %
RSTAR	M (IN)	THROAT RADIUS
DEXIT	M (IN)	ENGINE MAX. DIAMETER
F/E	N (LBF)	THRUST PER ELEMENT
ISPT	M/SEC (LBF-SEC/LBM)	ODE SPECIFIC IMPULSE
%KL	% (%)	KINETIC ISP LOSS
%DL	% (%)	DIVERGENCE ISP LOSS
%BLL	% (%)	BOUNDARY LAYER ISP LOSS
%FCL	% (%)	FUEL FILM COOLING ISP LOSS
%ERL	% (%)	ENERGY RELEASE ISP LOSS
ISPD	M/SEC (LBF-SEC/LBM)	ENGINE SPECIFIC IMPULSE

FLUORINE/HYDRAZINE ENGINE STUDY

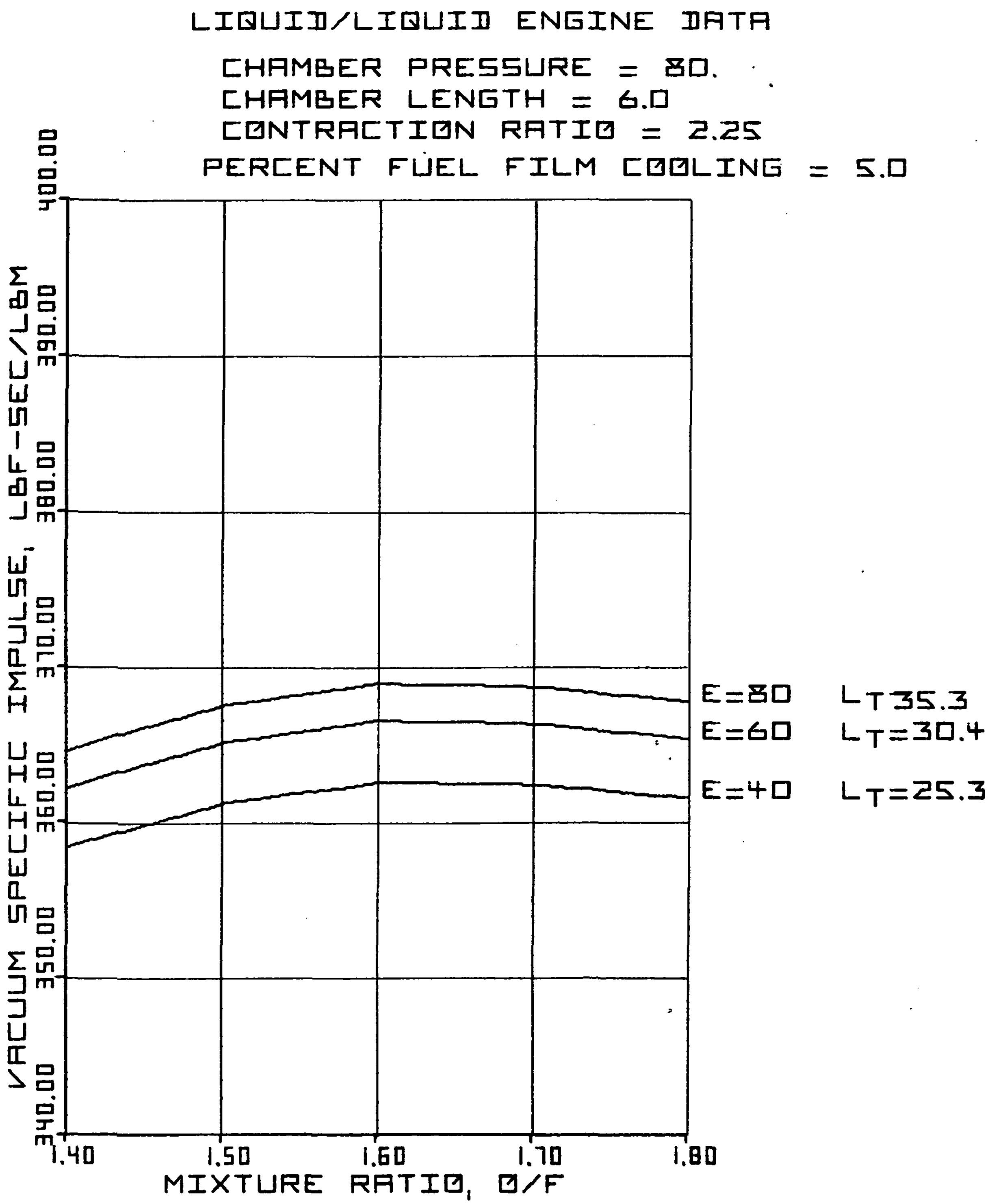
LIQUID/LIQUID ENGINE DATA

CHAMBER PRESSURE = 80.
CHAMBER LENGTH = 6.0
CONTRACTION RATIO = 1.50
PERCENT FUEL FILM COOLING = 5.0



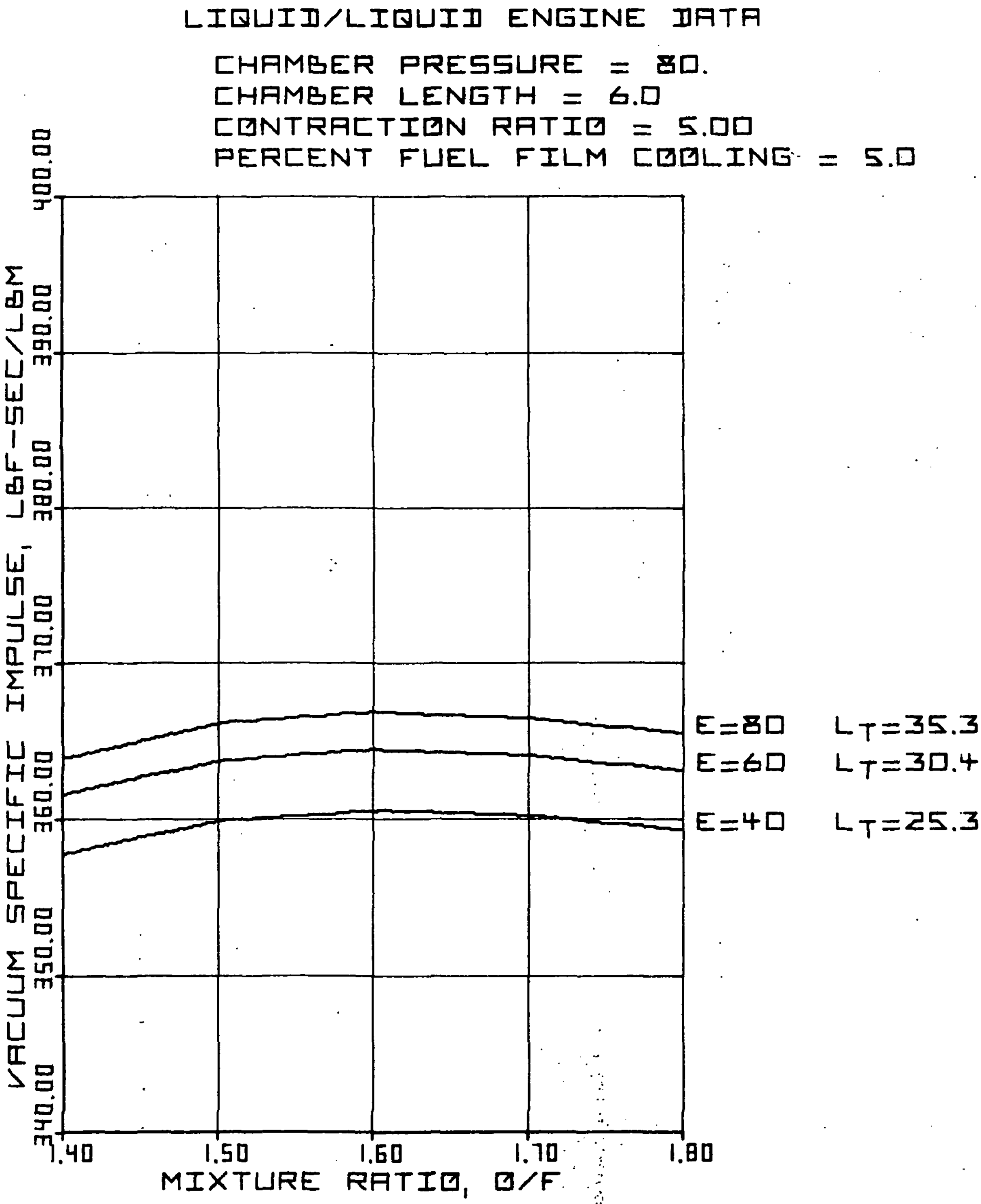
-ID-01 +27129 23 SEP 74 095252

FLUORINE/HYDRAZINE ENGINE STUDY



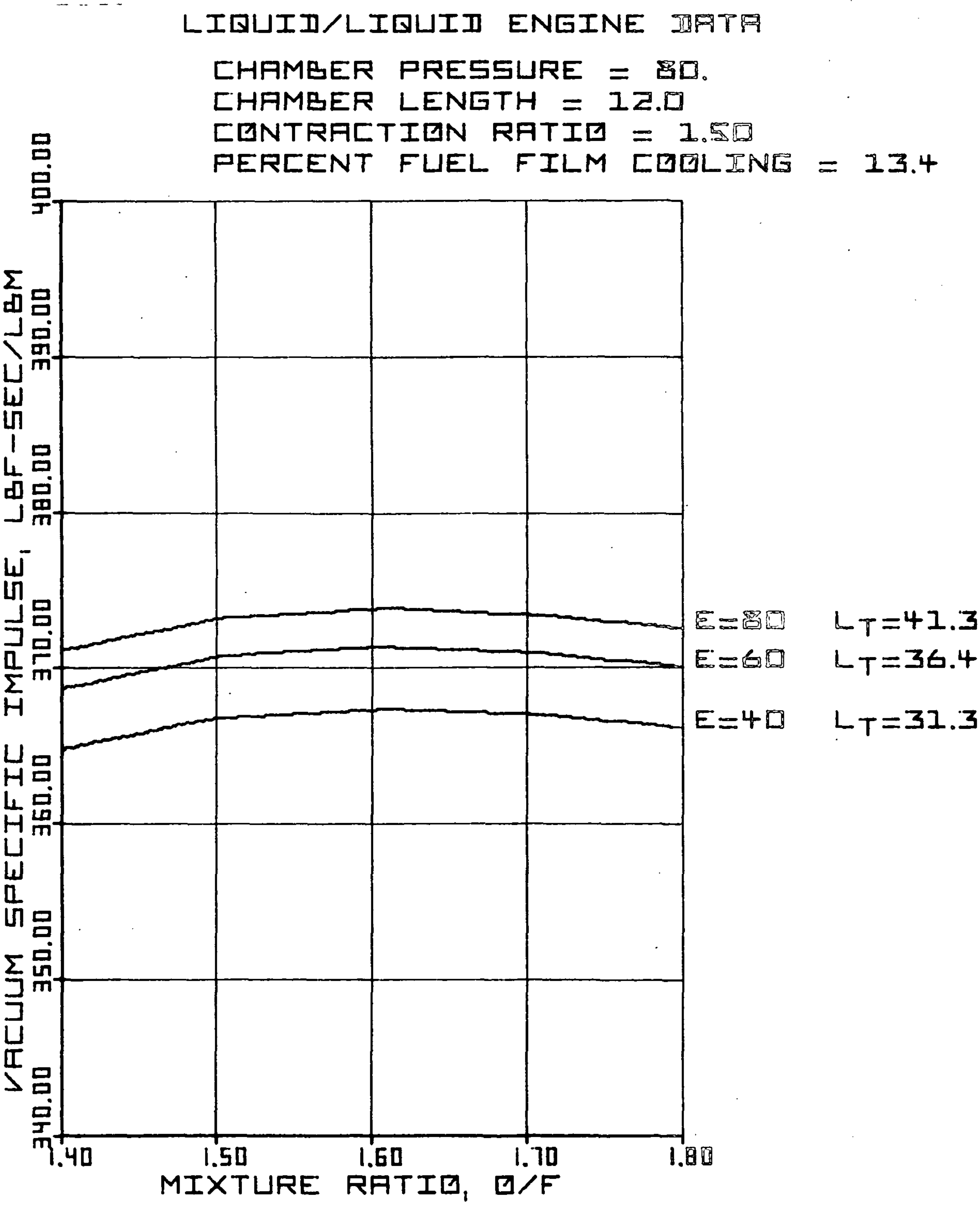
112

FLUORINE/HYDRAZINE
ENGINE STUDY



113

FLUORINE/HYDRAZINE ENGINE STUDY



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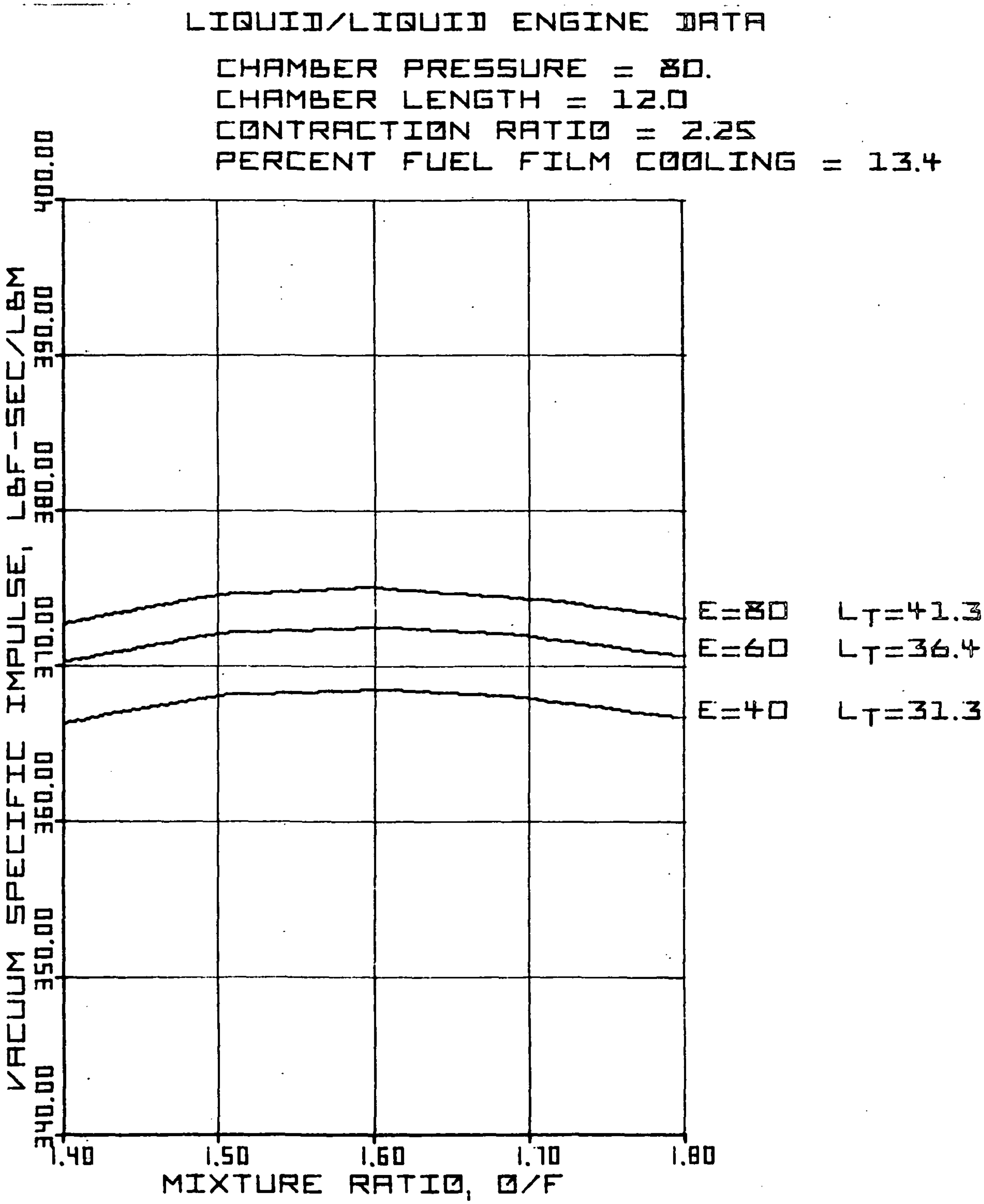

FLUORINE/HYDRAZINE ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

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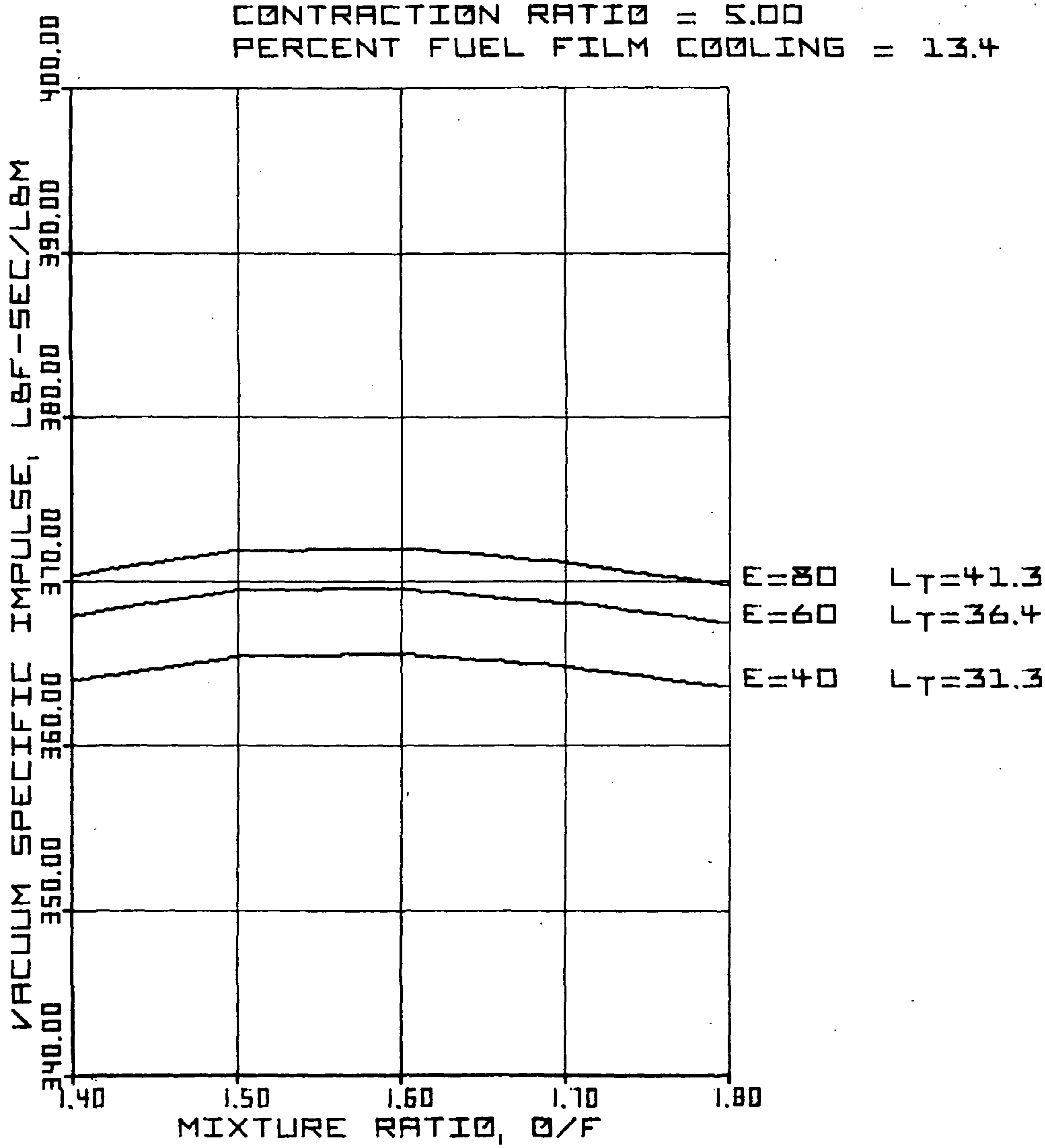
CHAMBER LENGTH = 12.0
CONTRACTION RATIO = 5.00
PERCENT FUEL FILM COOLING = 13.4



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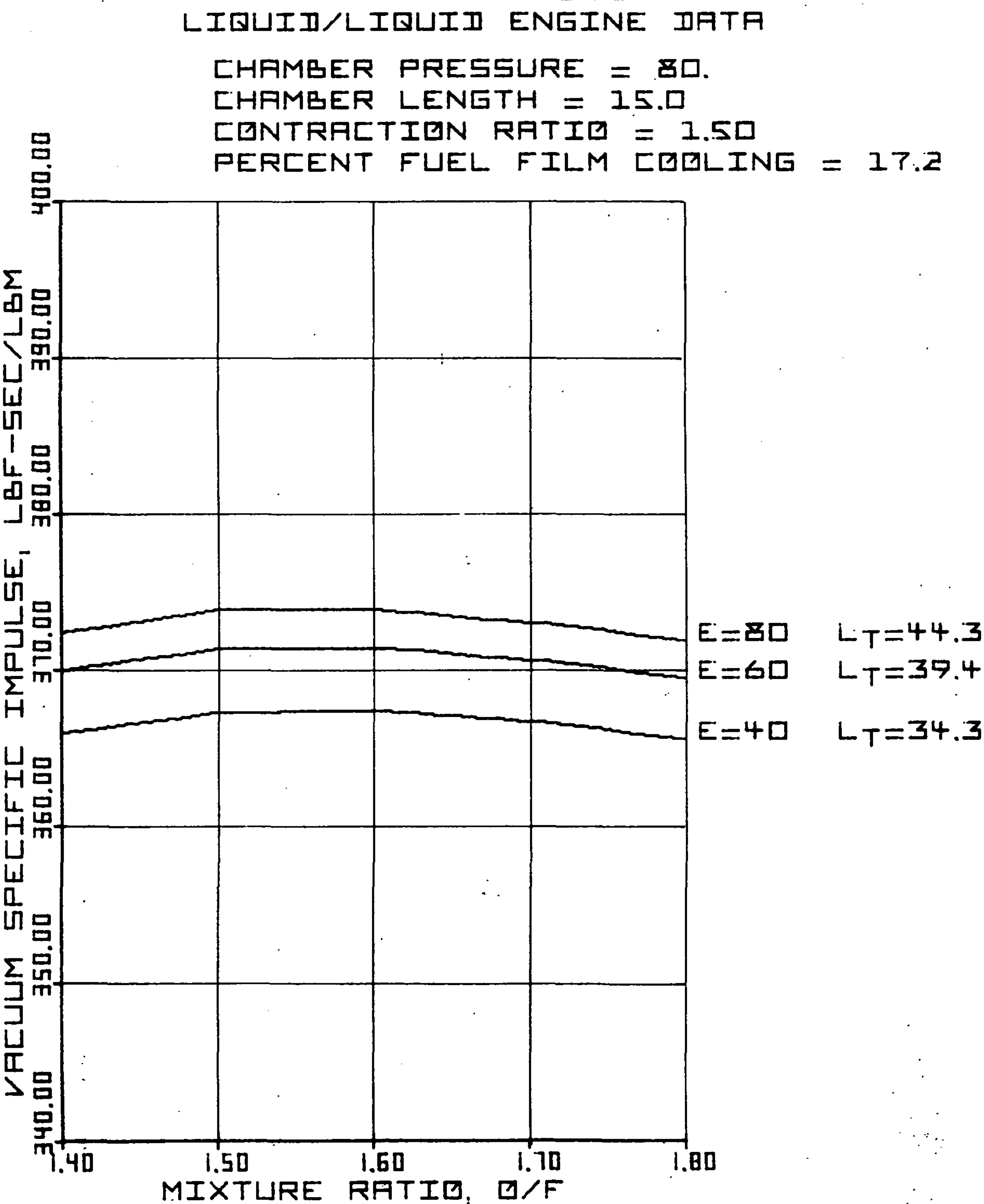

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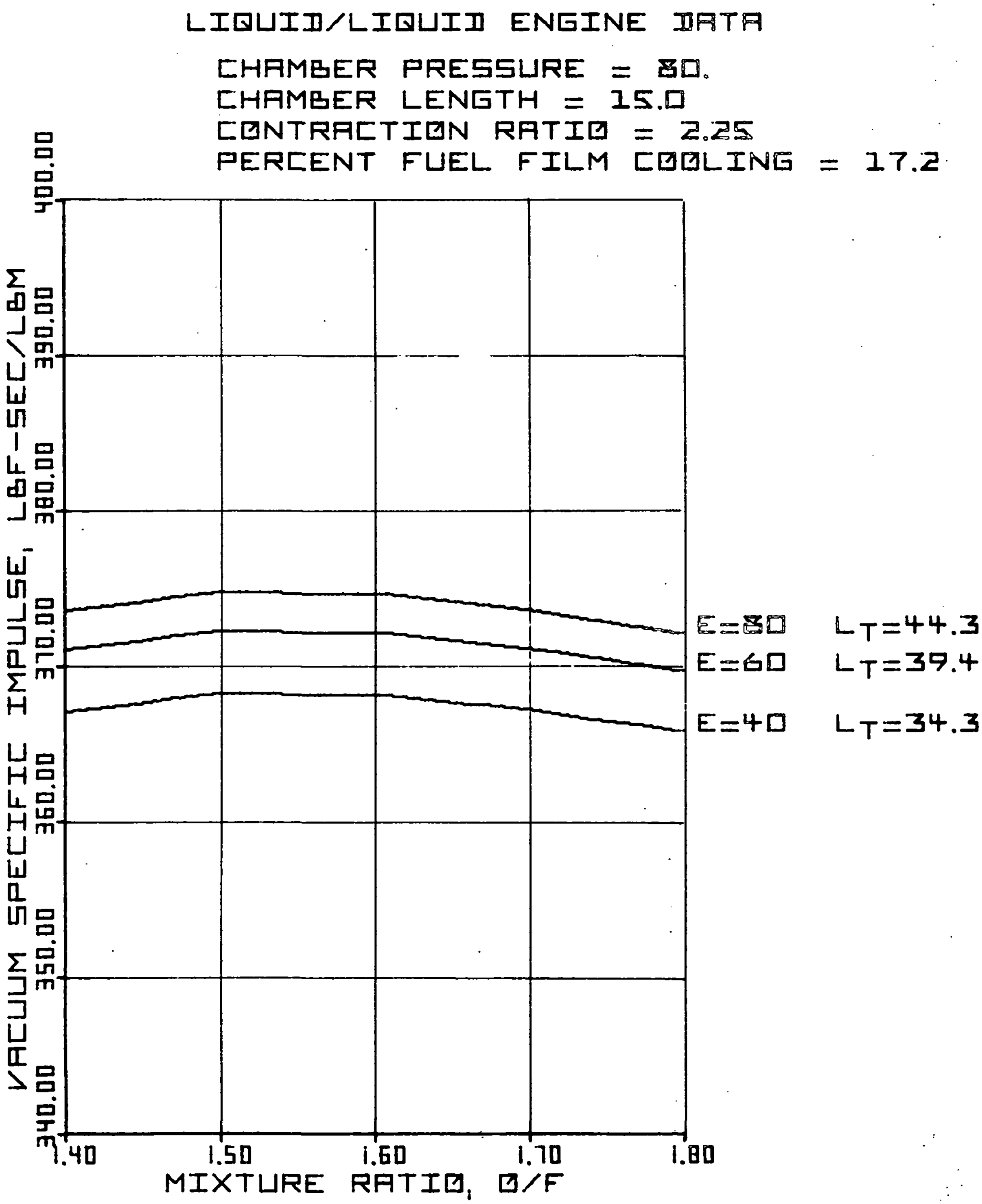

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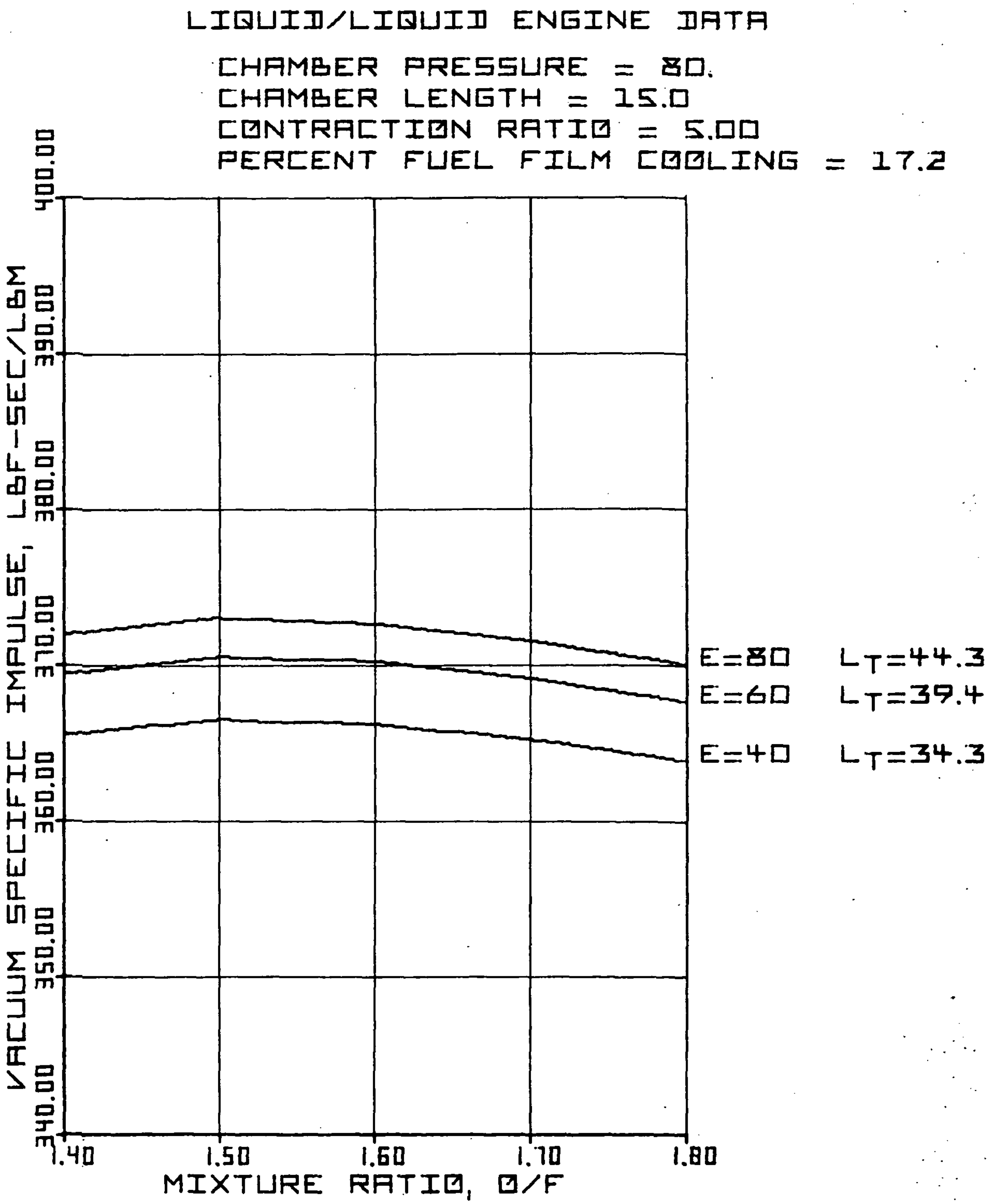

119

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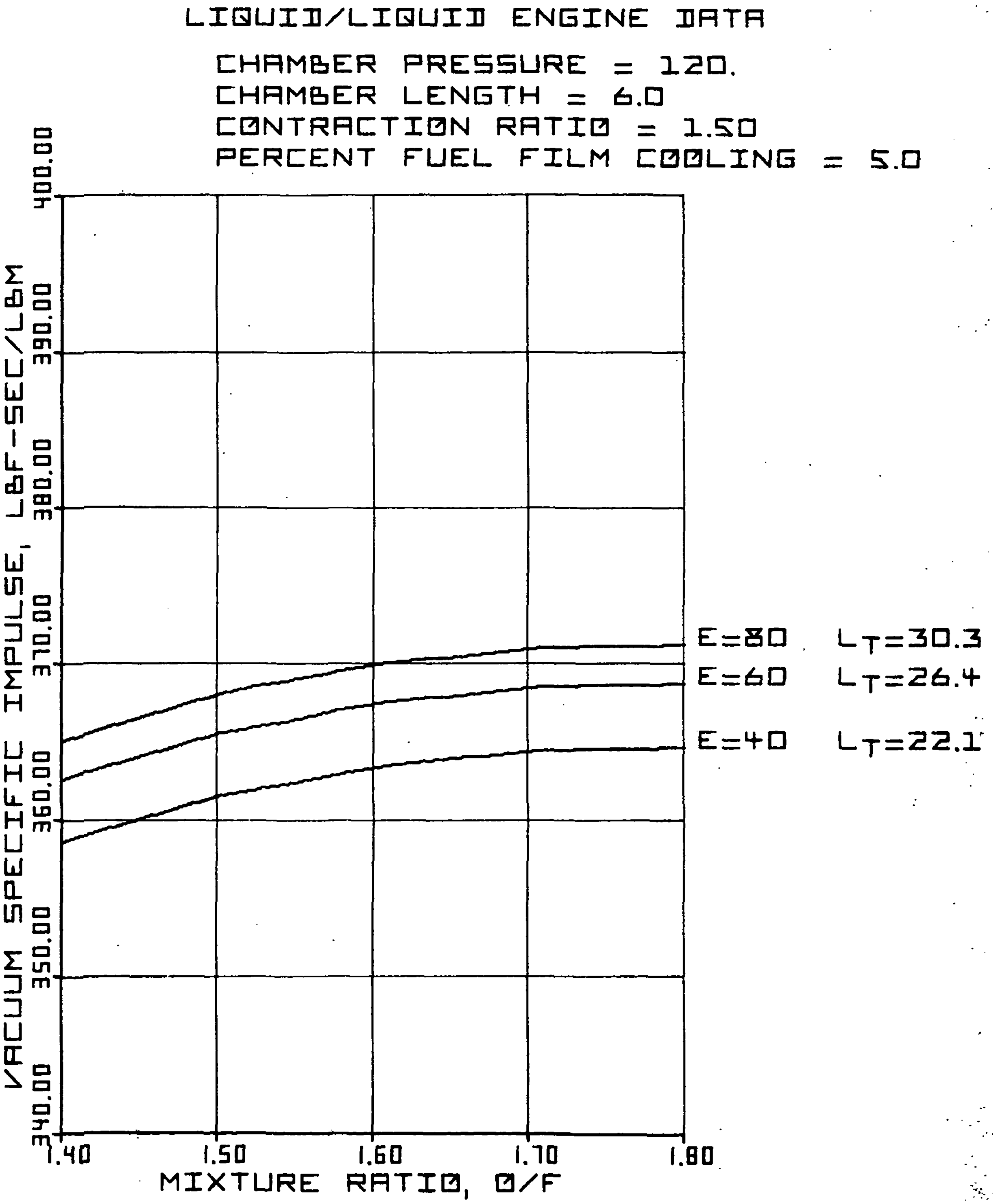

FLUORINE/HYDRAZINE ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

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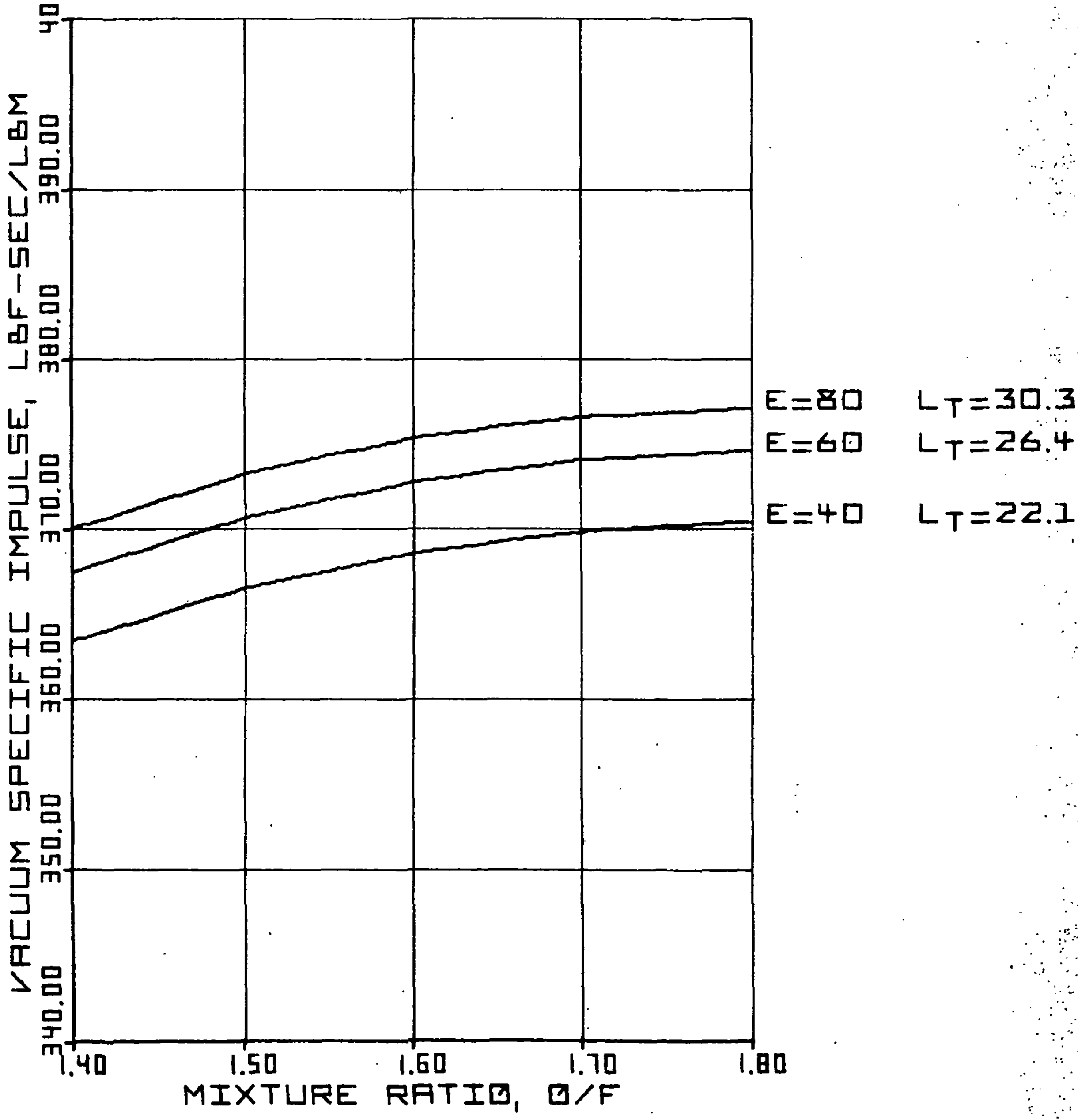
CONTRACTION RATIO = 2.25
PERCENT FUEL FILM COOLING = 5.0



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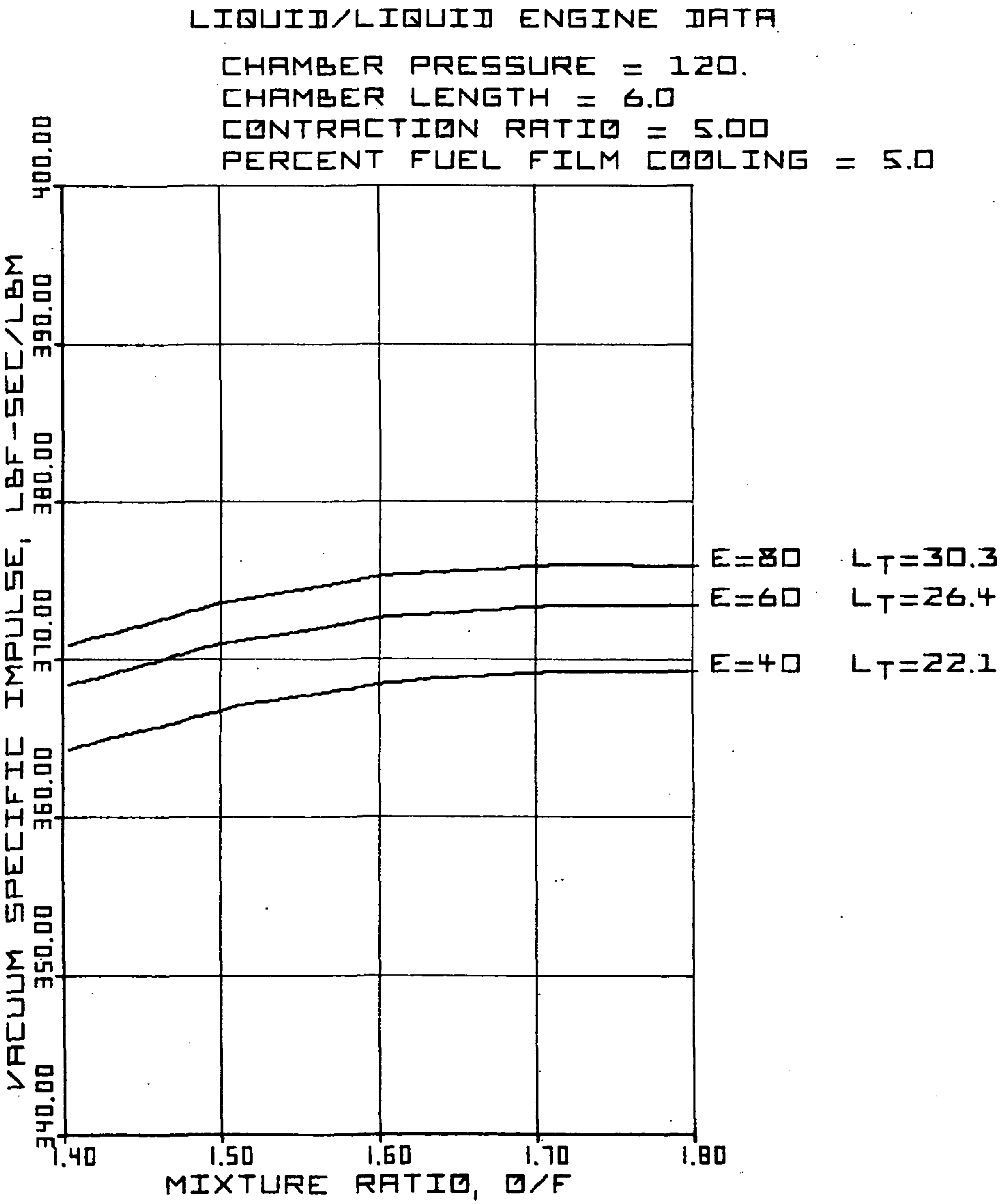

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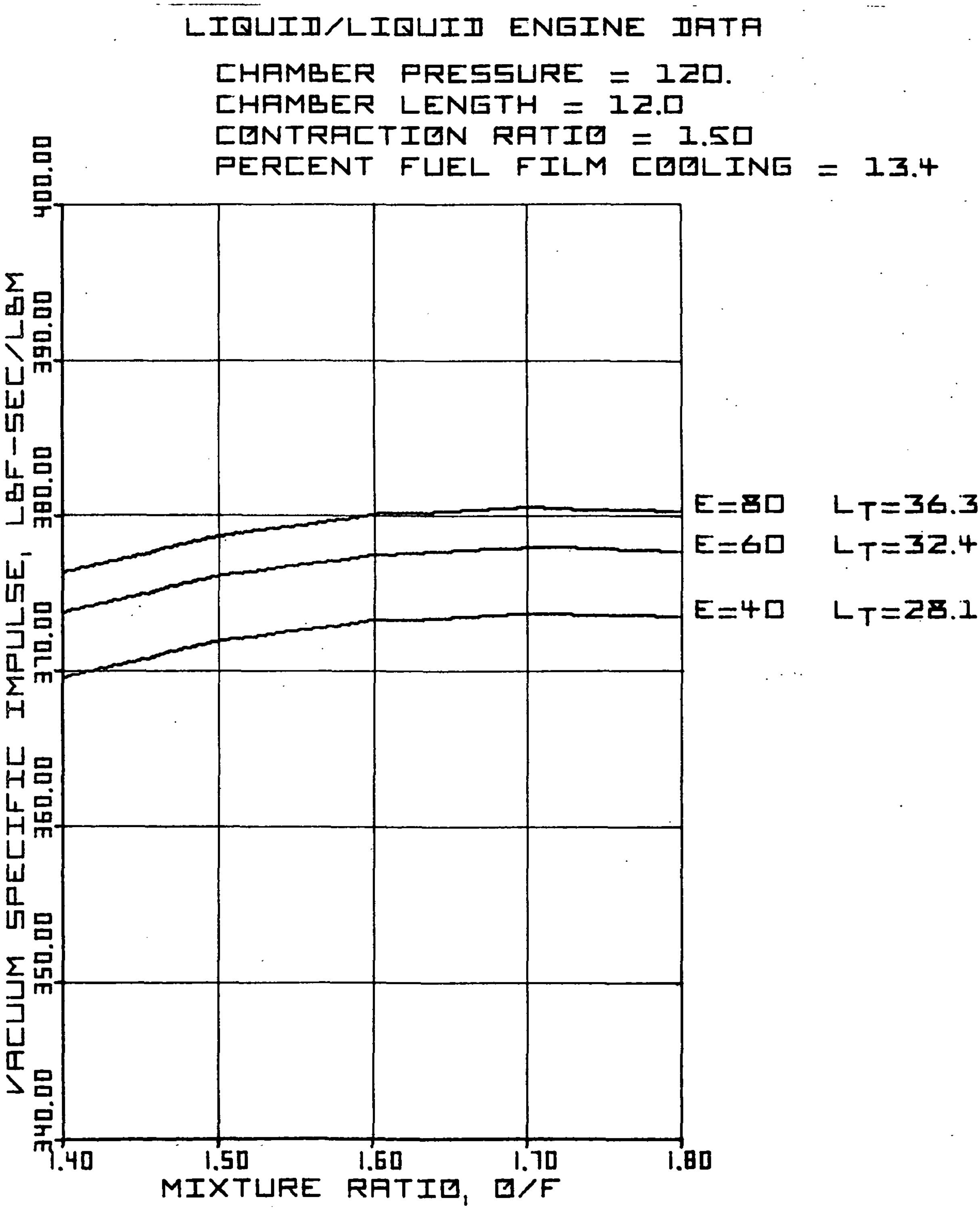

123

FLUORINE/HYDRAZINE ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

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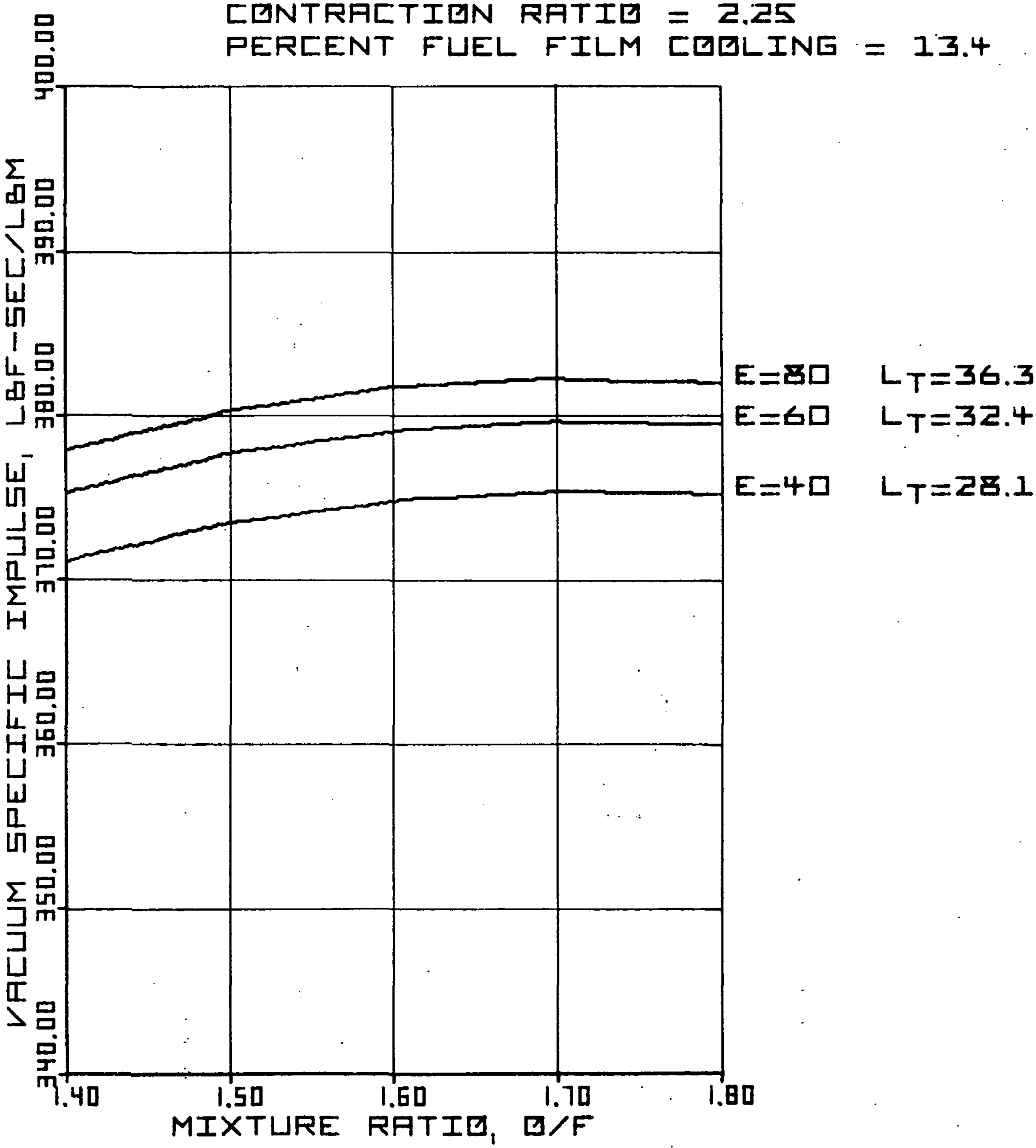
CHAMBER LENGTH = 12.0
CONTRACTION RATIO = 2.25
PERCENT FUEL FILM COOLING = 13.4



124

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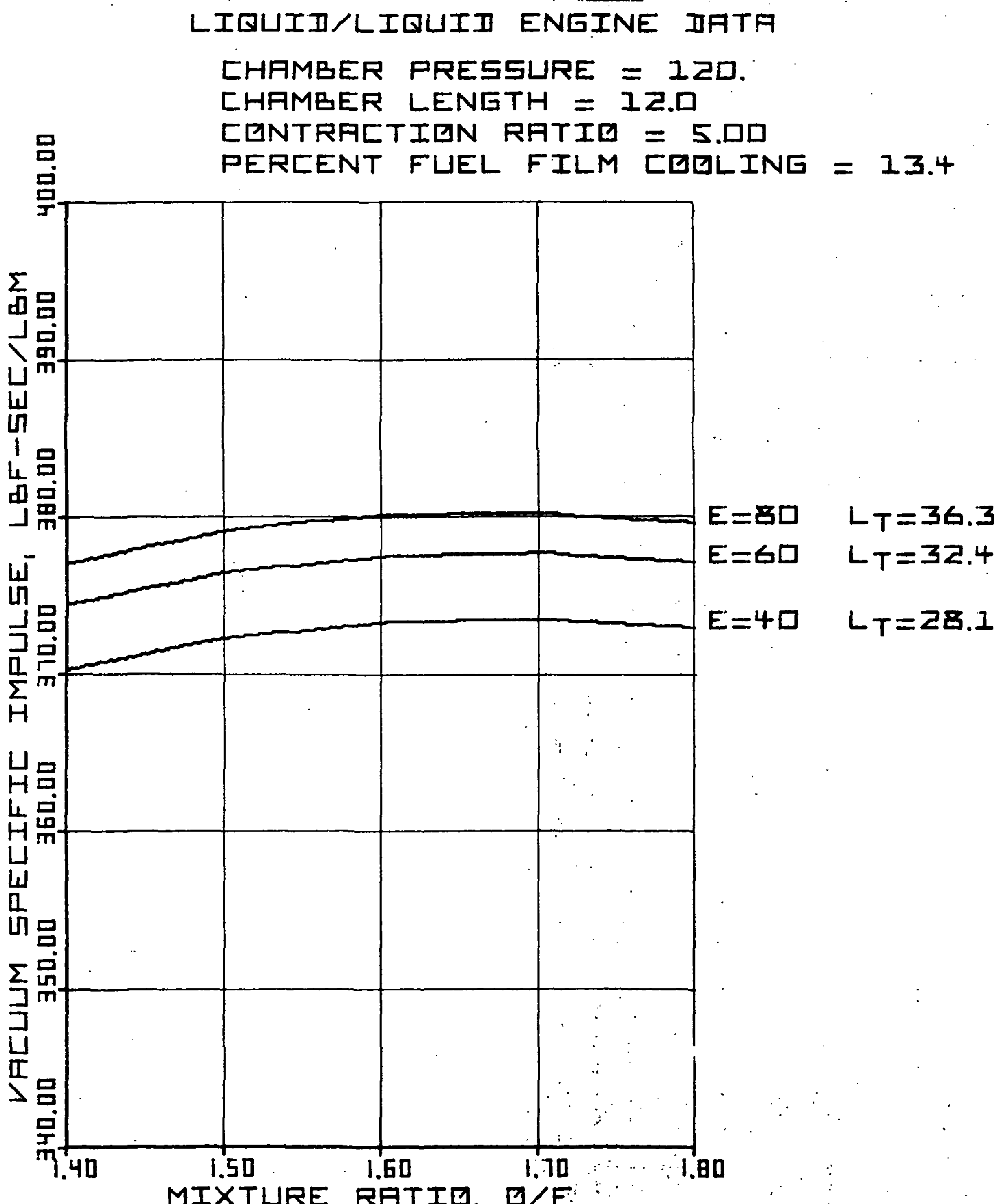

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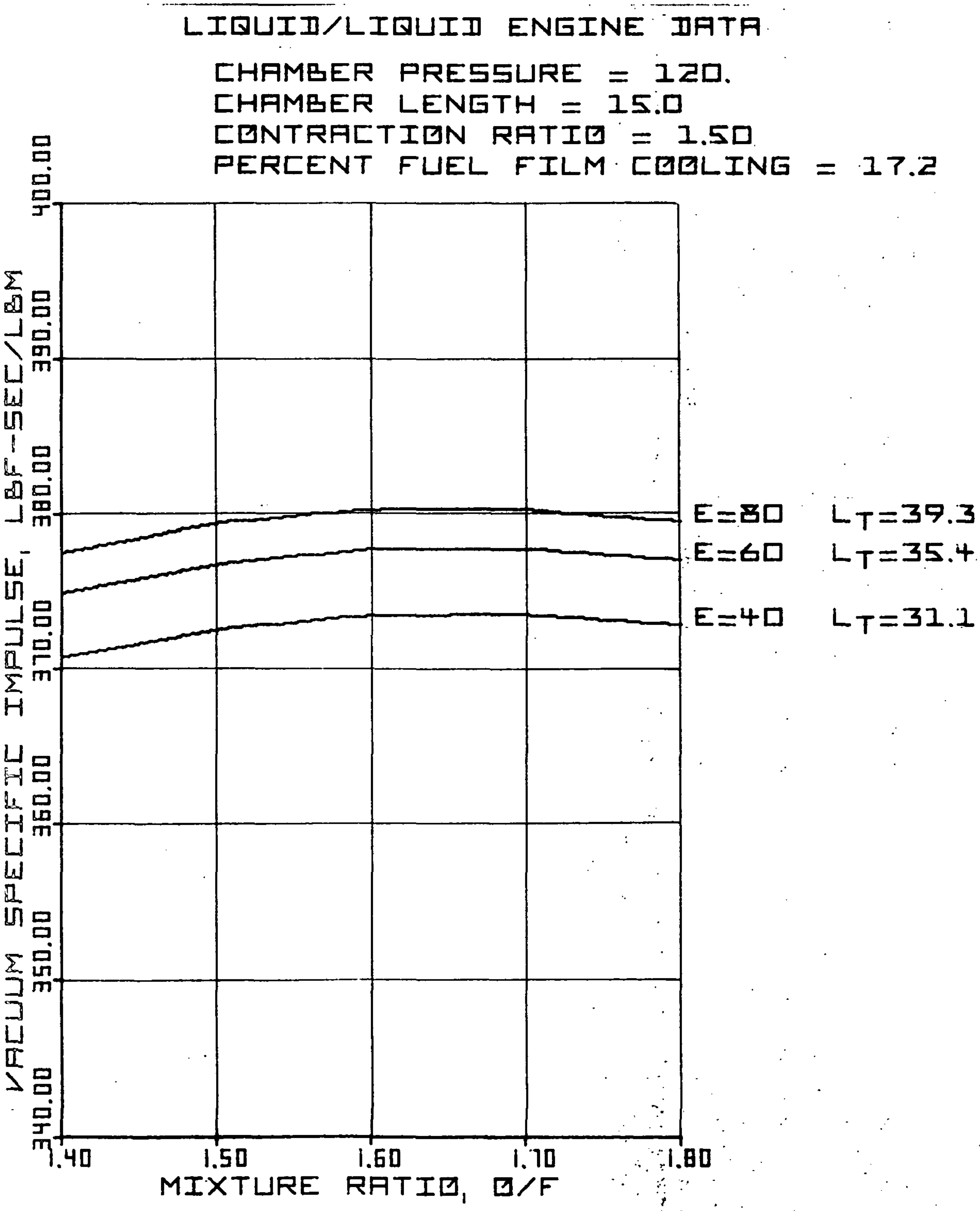
FLUORINE/HYDRAZINE ENGINE STUDY



126

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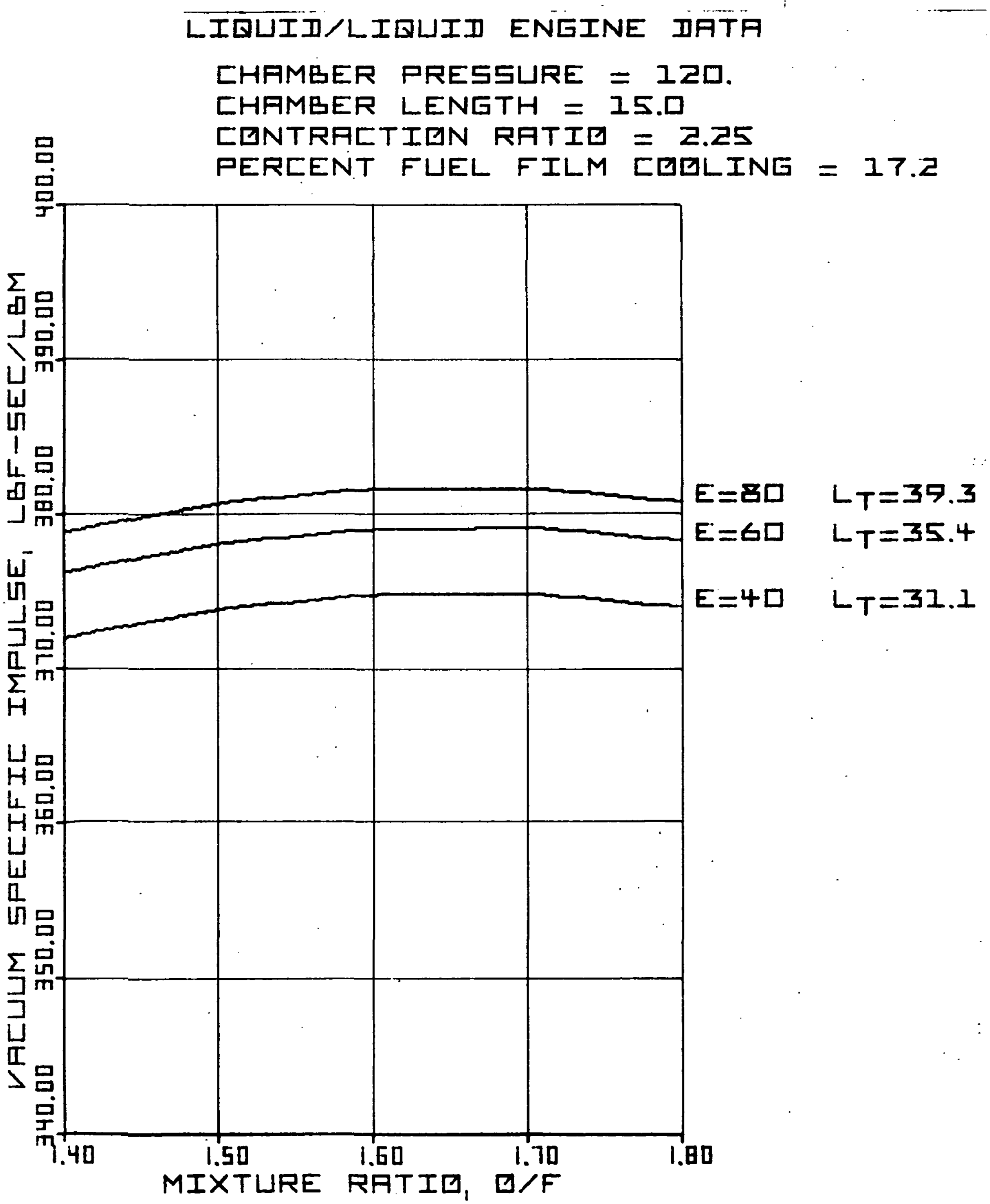
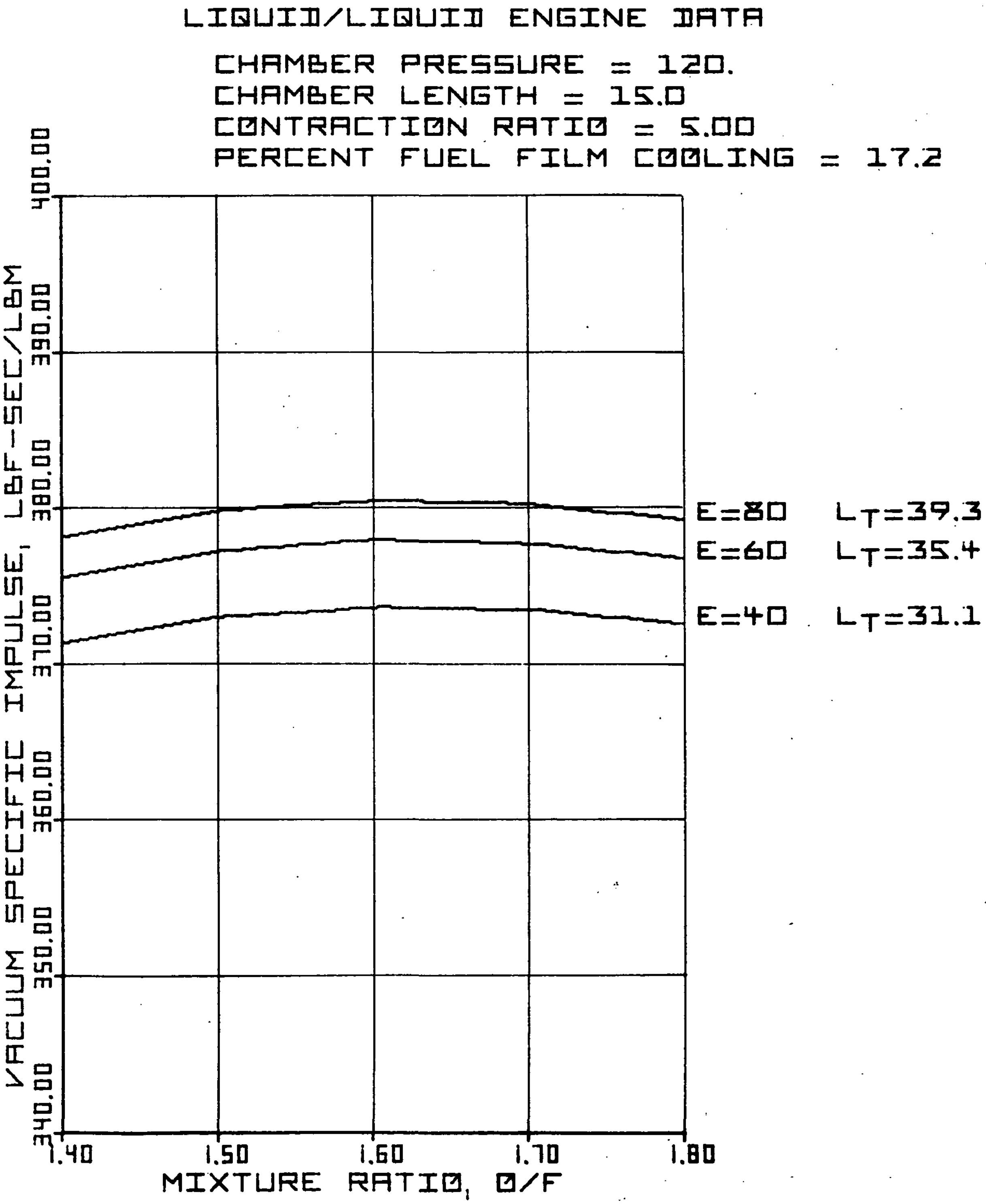


127

FLUORINE/HYDRAZINE ENGINE STUDY



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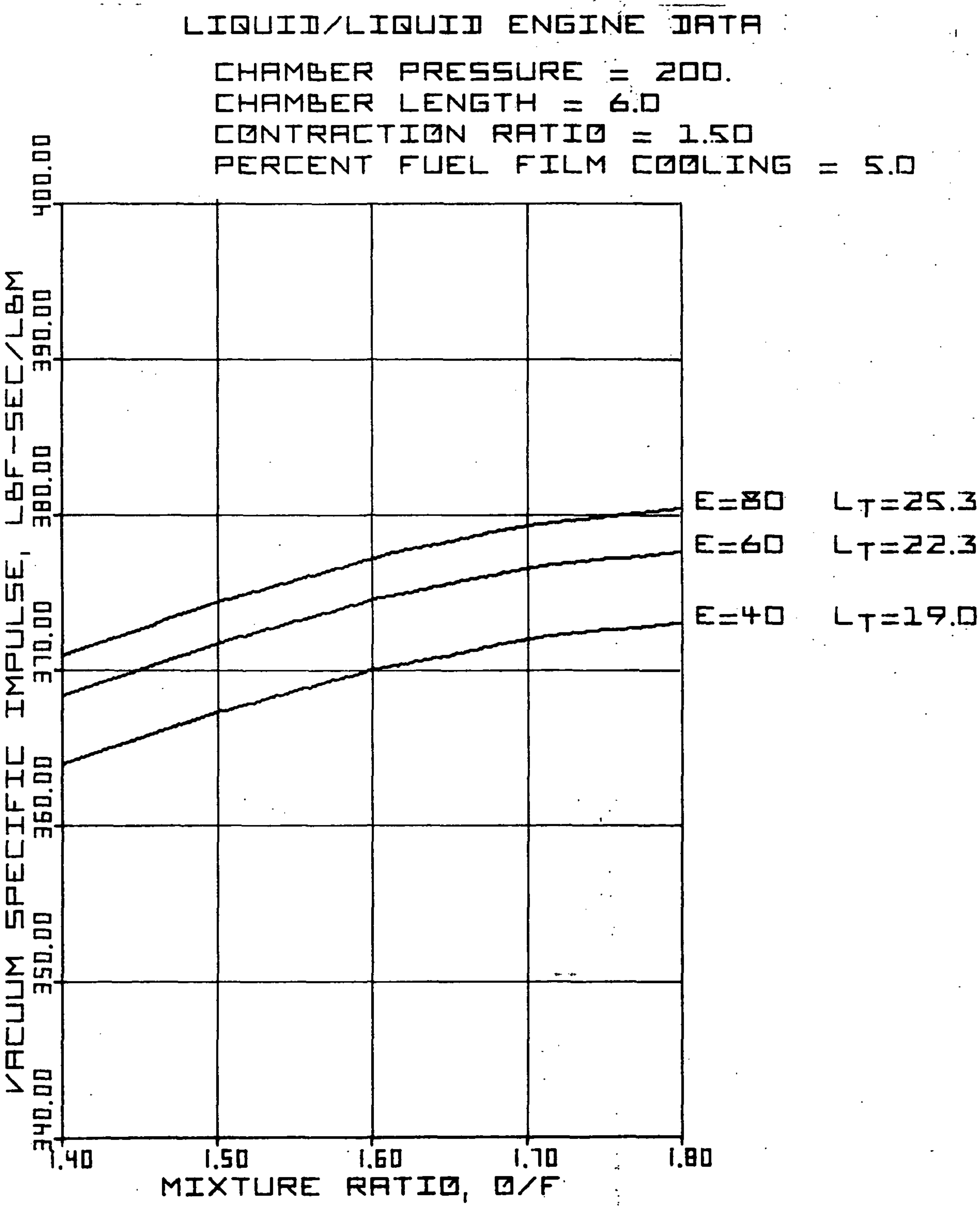

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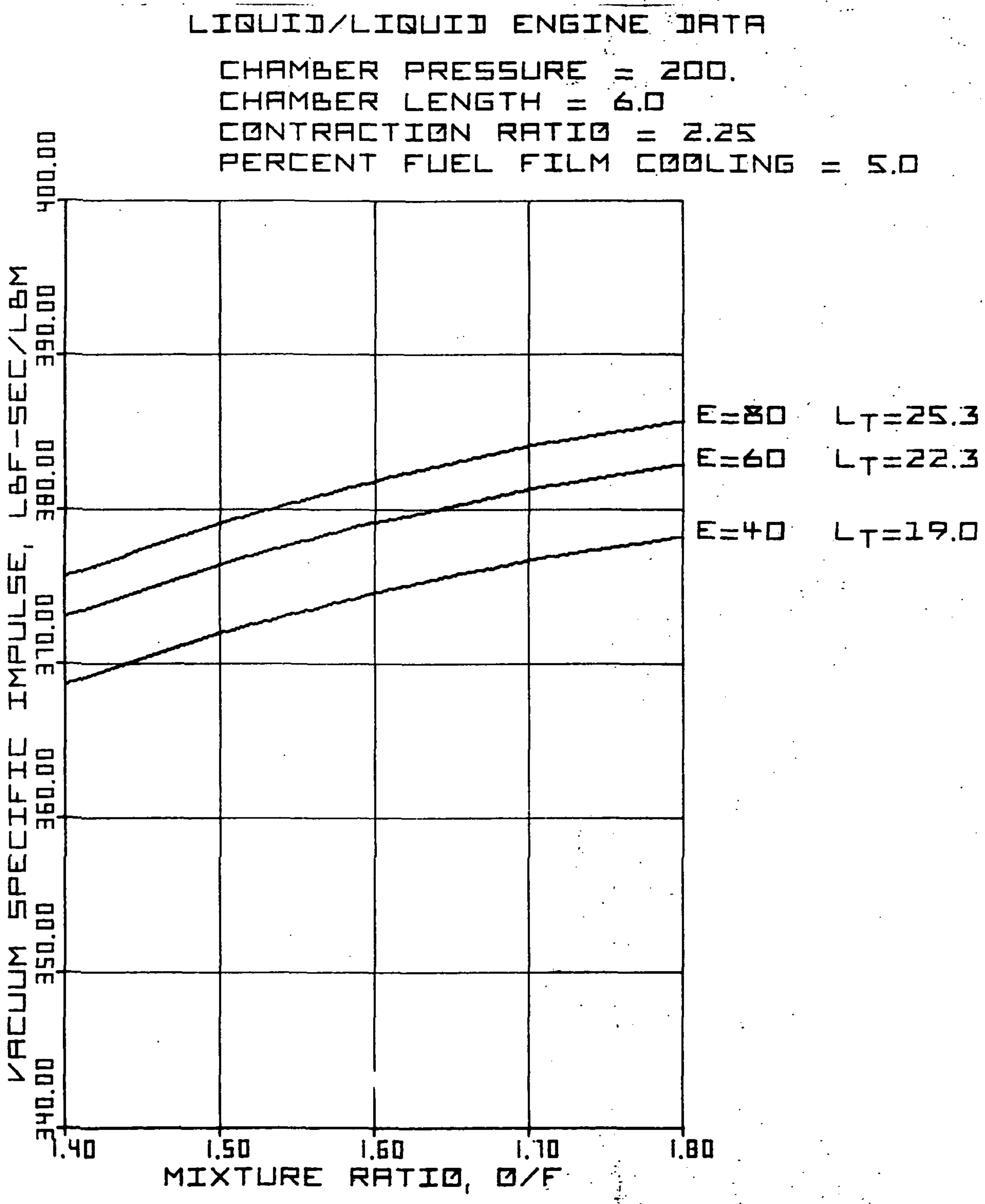
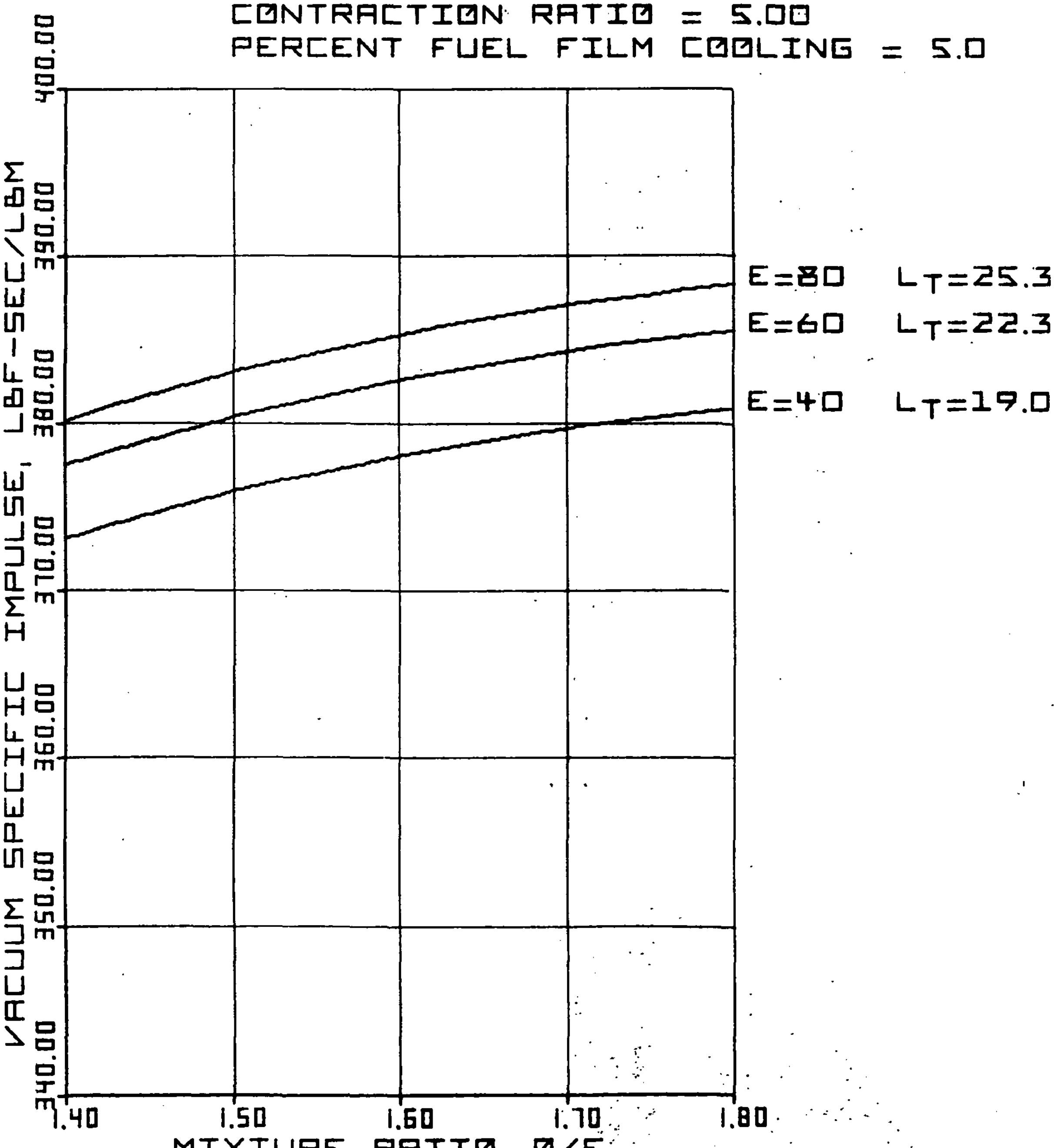


30

FLUORINE/HYDRAZINE ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

CHAMBER PRESSURE = 200.
CHAMBER LENGTH = 6.0
CONTRACTION RATIO = 5.00
PERCENT FUEL FILM COOLING = 5.0



FLUORINE/HYDRAZINE ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

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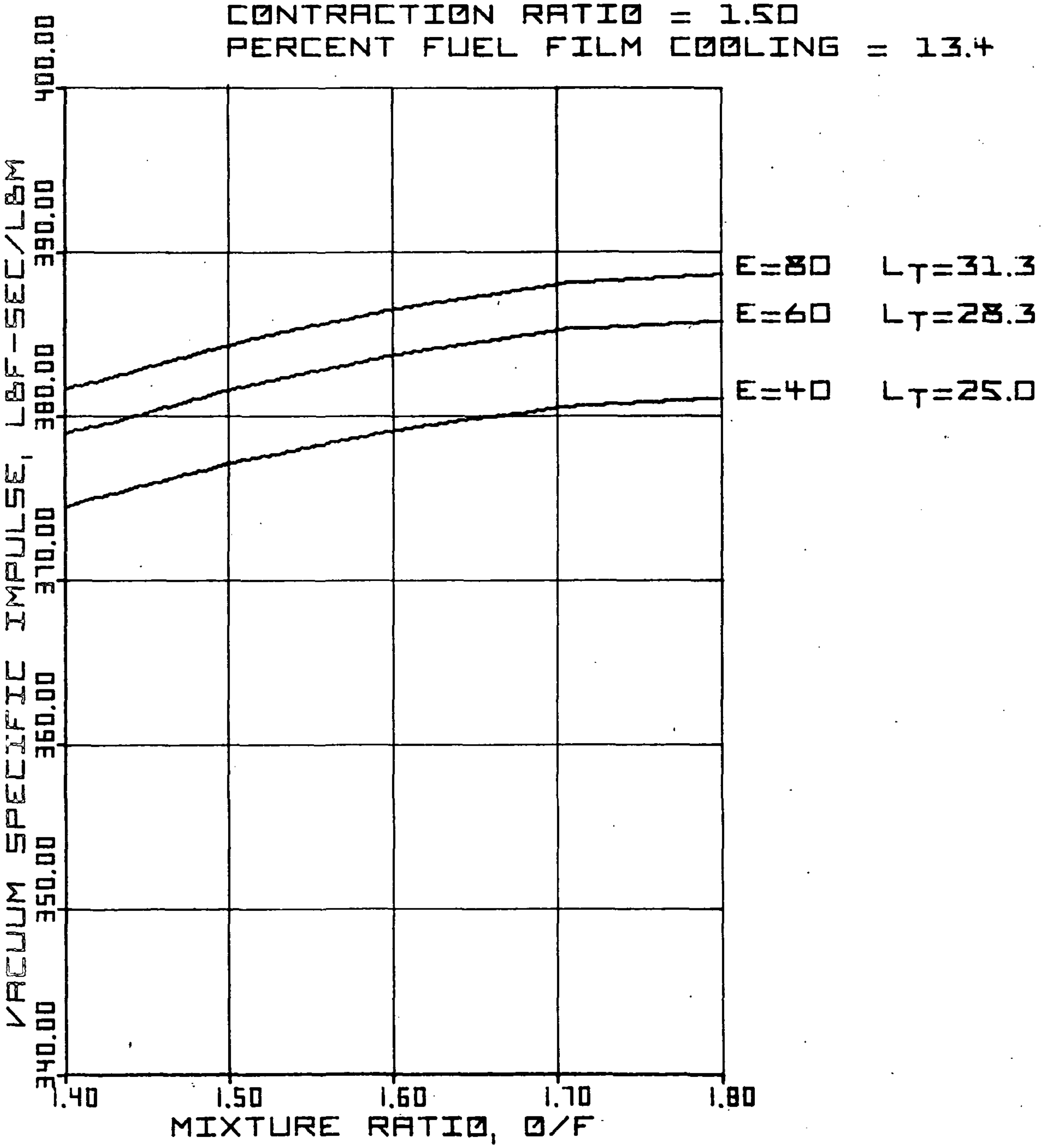
CHAMBER LENGTH = 12.0
CONTRACTION RATIO = 1.50
PERCENT FUEL FILM COOLING = 13.4



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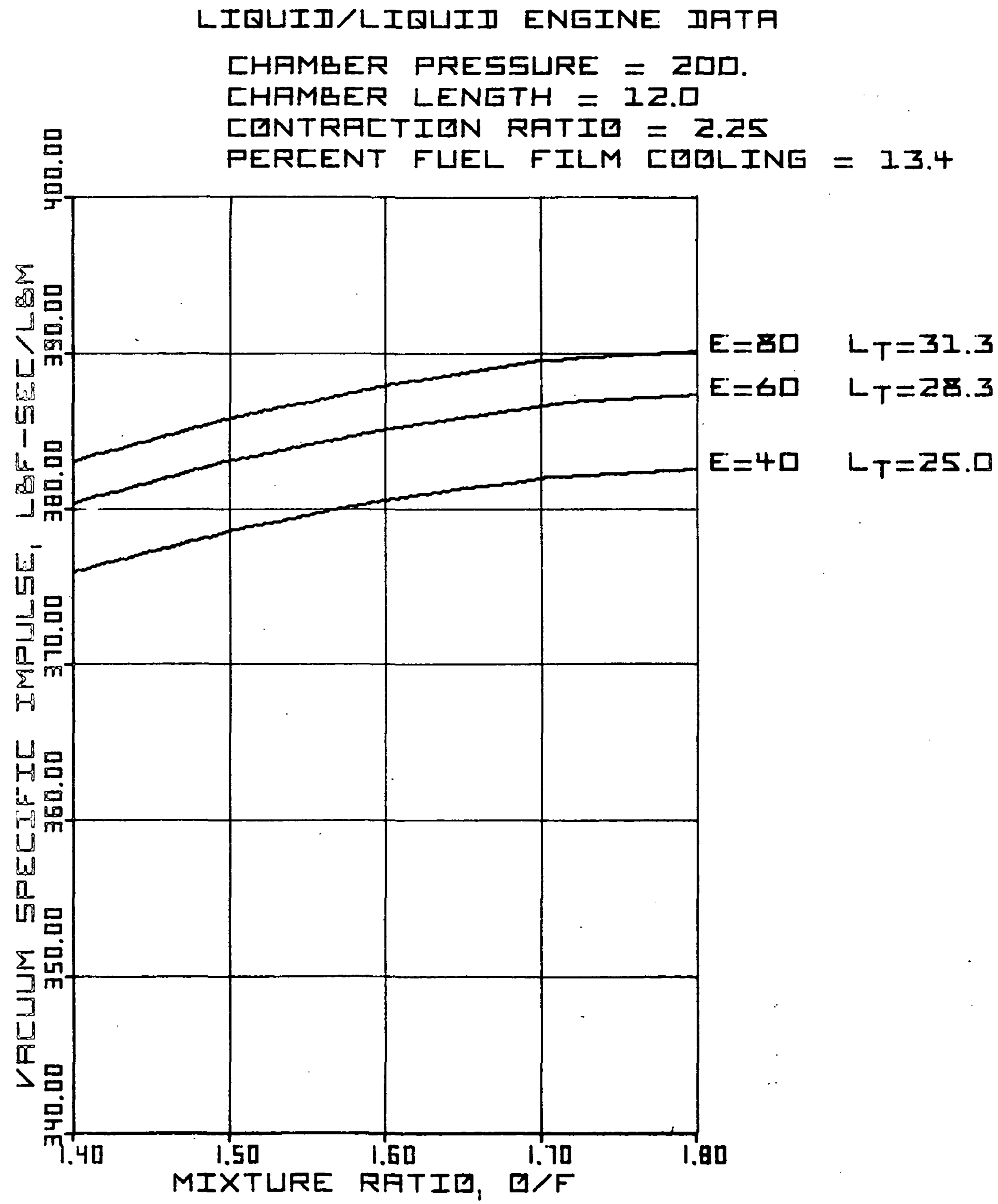
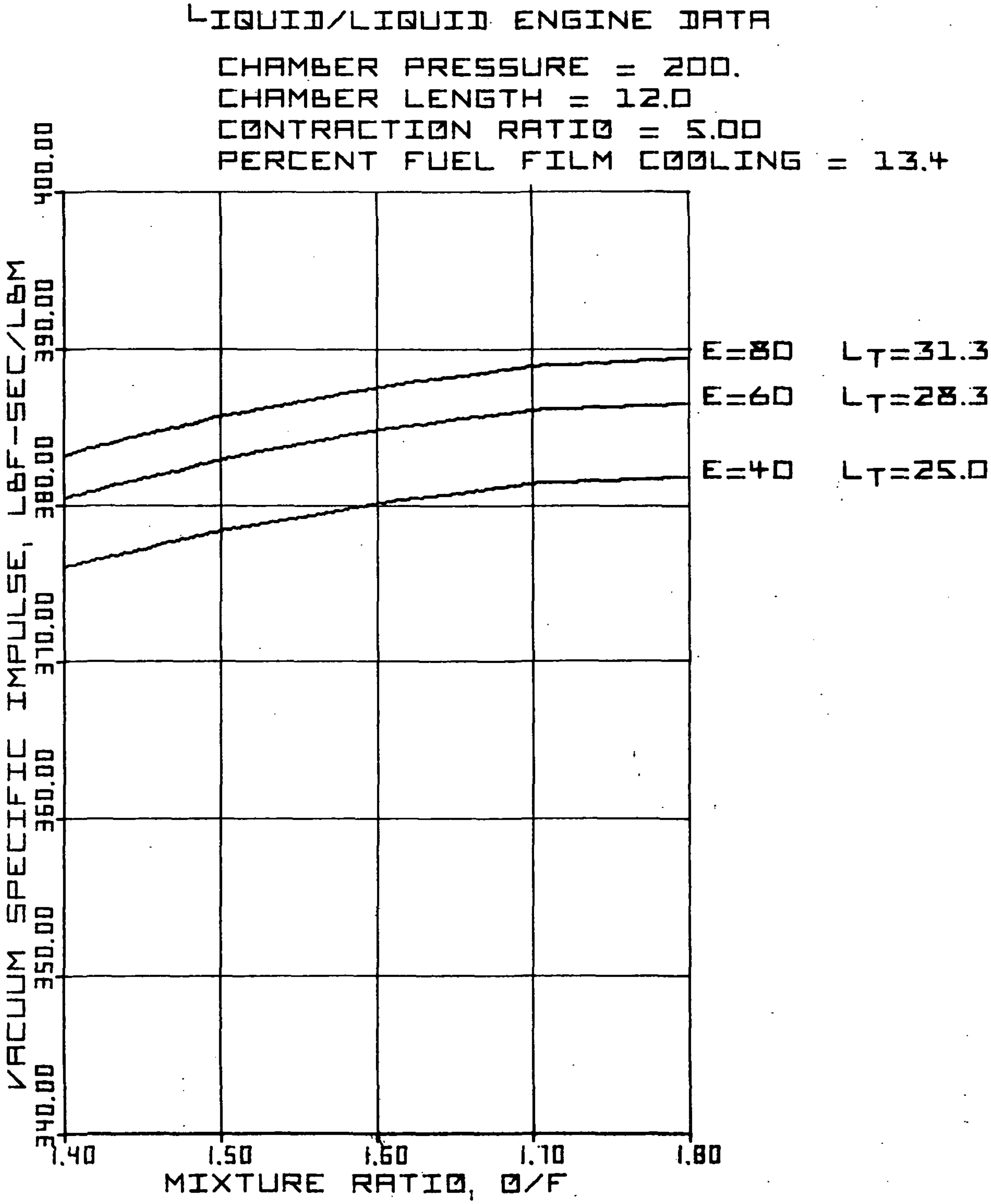


133

FLUORINE/HYDRAZINE ENGINE STUDY



134

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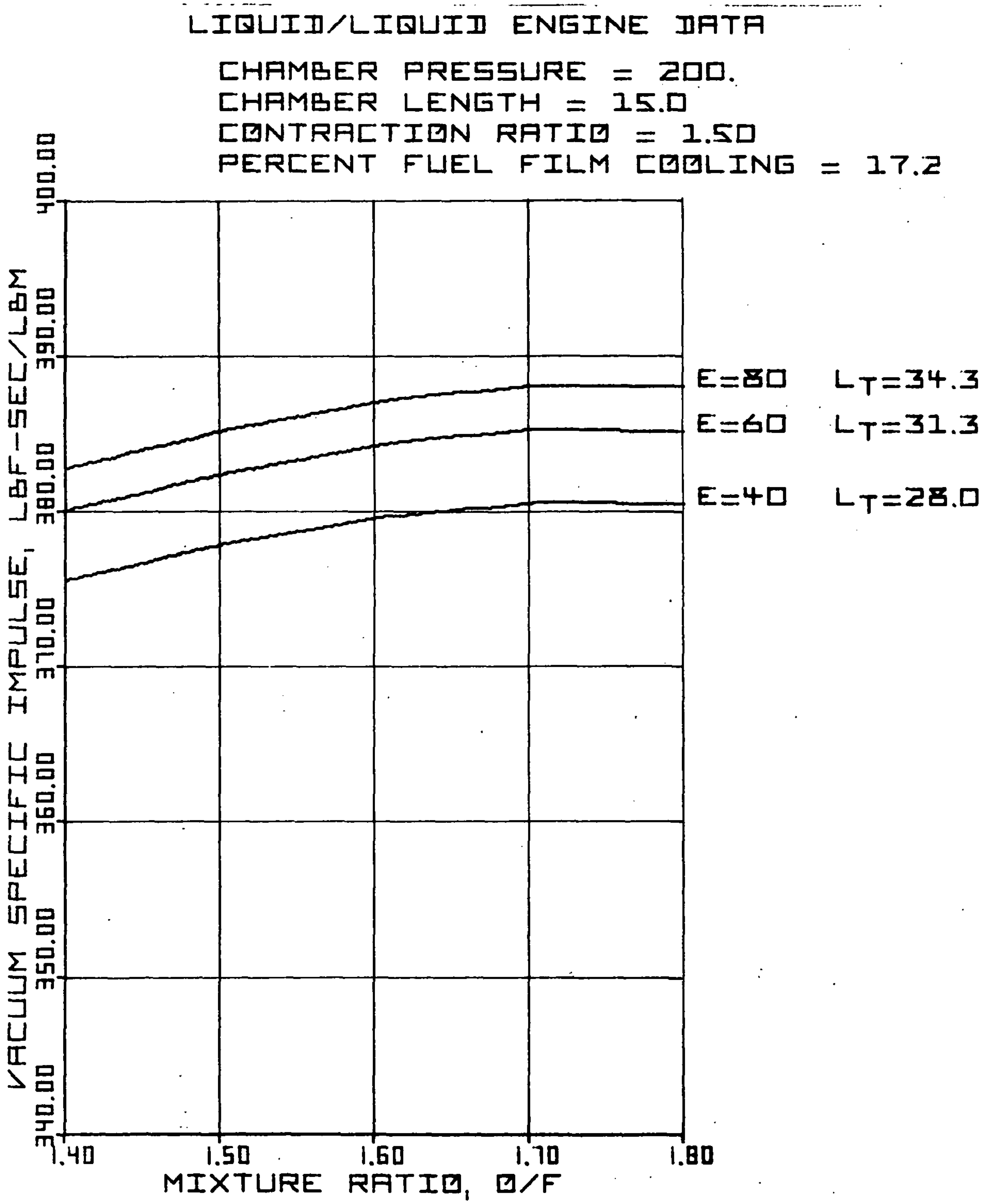
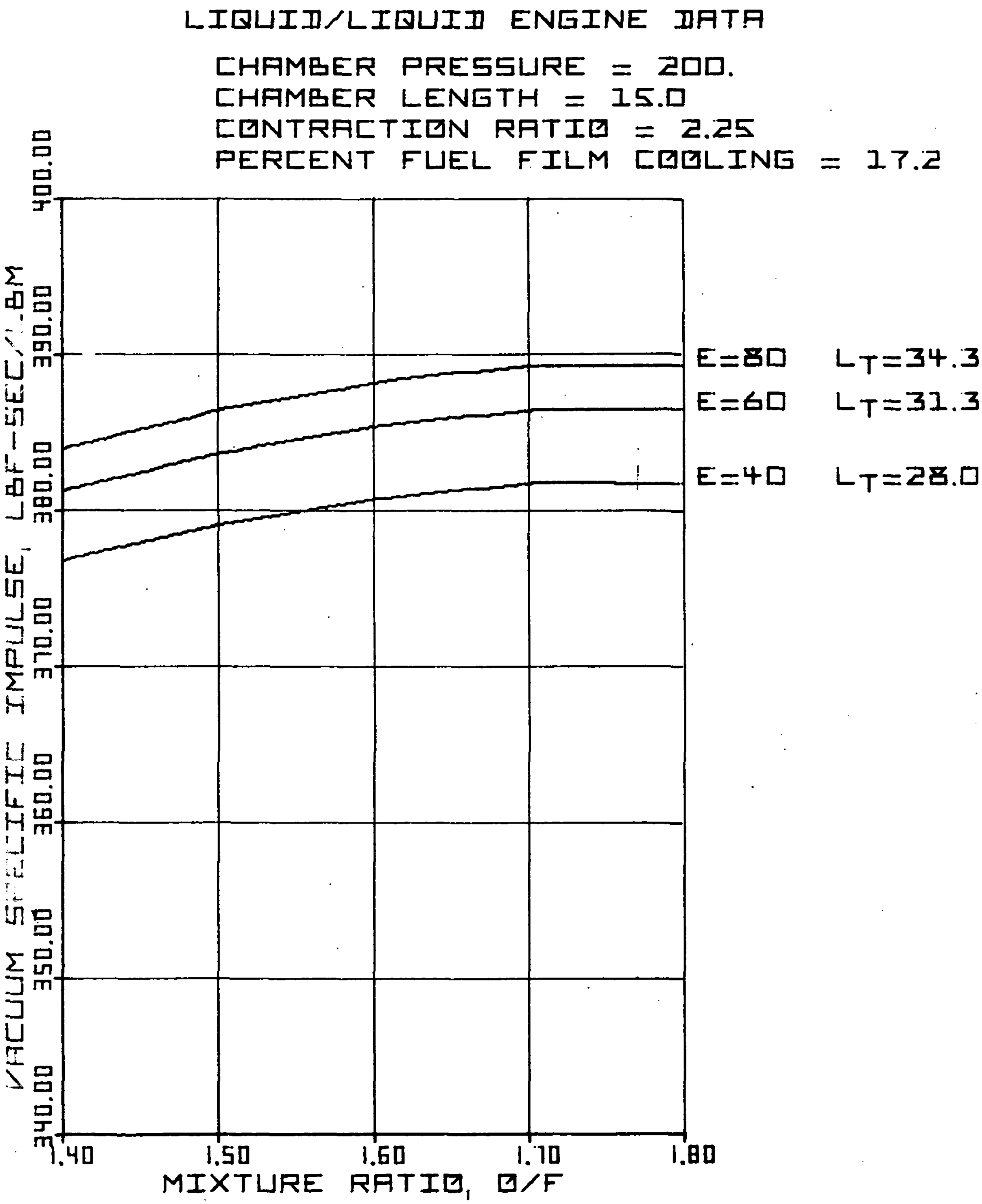


FLUORINE/HYDRAZINE
ENGINE STUDY



FLUORINE/HYDRAZINE
ENGINE STUDY

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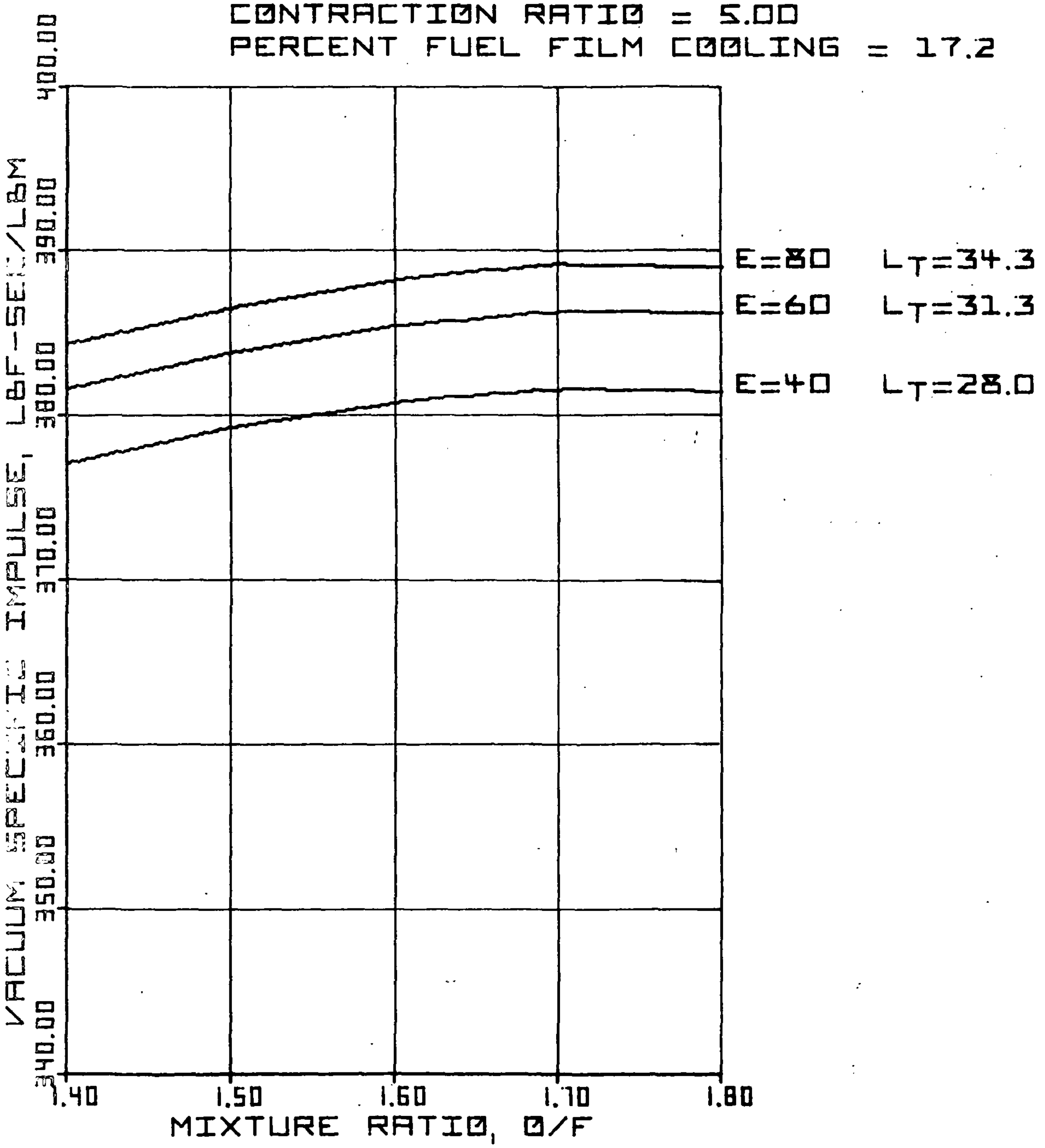


137

APPENDIX A

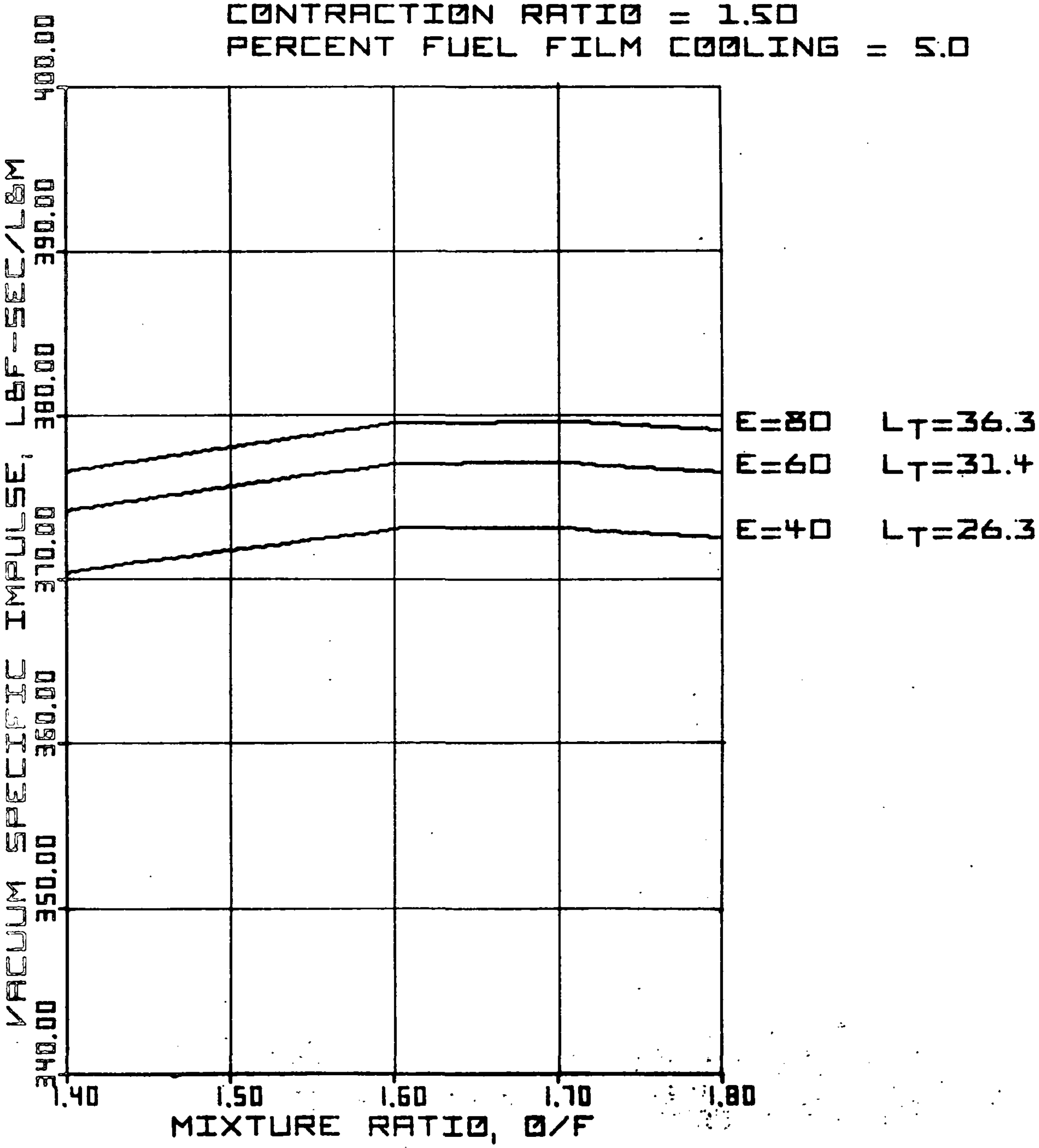
FIGURE SET B

BIMODAL ENGINE SPECIFIC IMPULSE VERSUS MIXTURE RATIO

FLUORINE/HYDRAZINE ENGINE STUDY

BIMODE ENGINE DATA

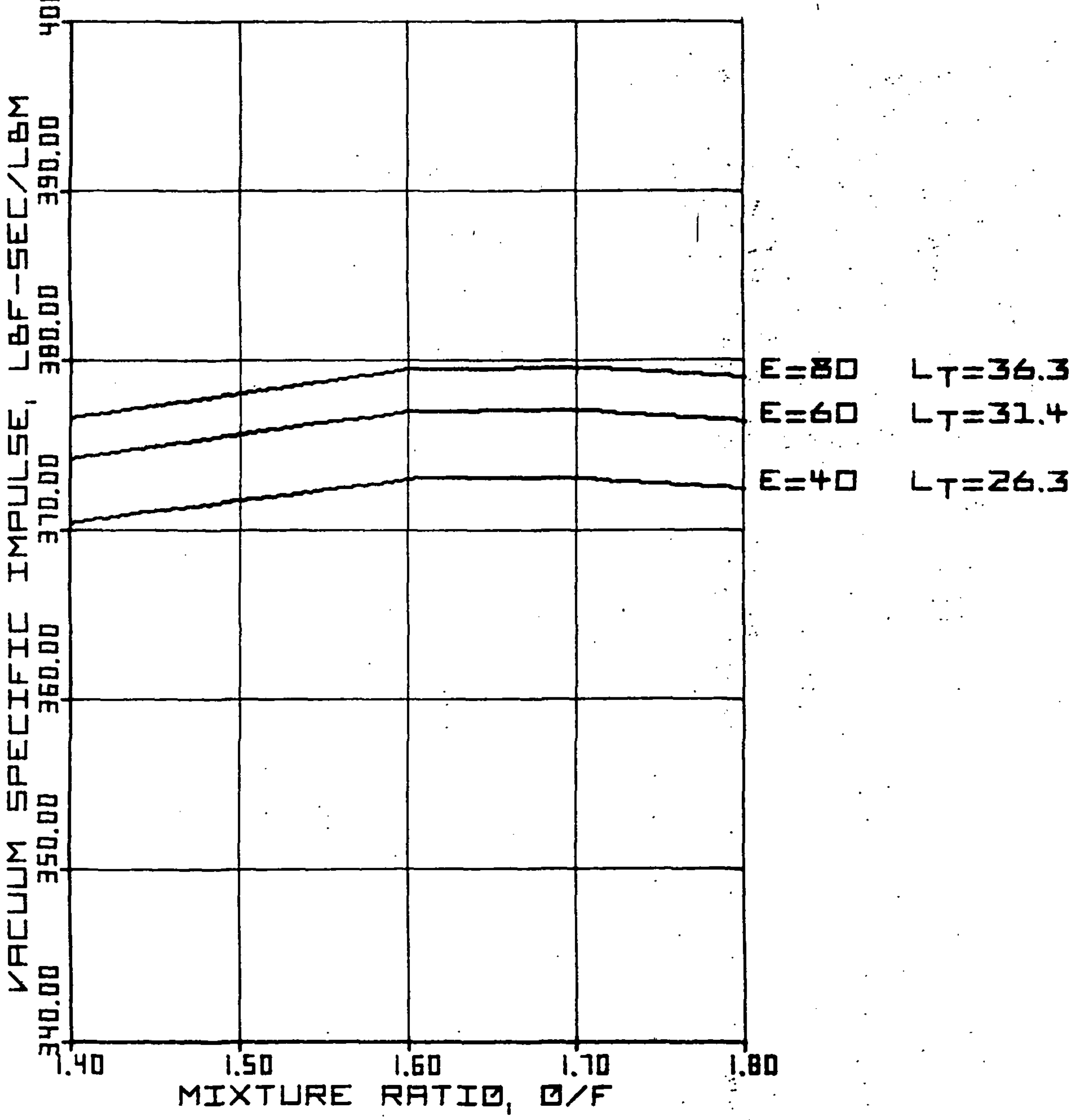
CHAMBER PRESSURE = 80.
CHAMBER LENGTH = 6.0
CONTRACTION RATIO = 1.50
PERCENT FUEL FILM COOLING = 5.0



FLUORINE/HYDRAZINE ENGINE STUDY

BIMODE ENGINE DATA

CHAMBER PRESSURE = 80.
CHAMBER LENGTH = 6.0
CONTRACTION RATIO = 2.50
PERCENT FUEL FILM COOLING = 5.0



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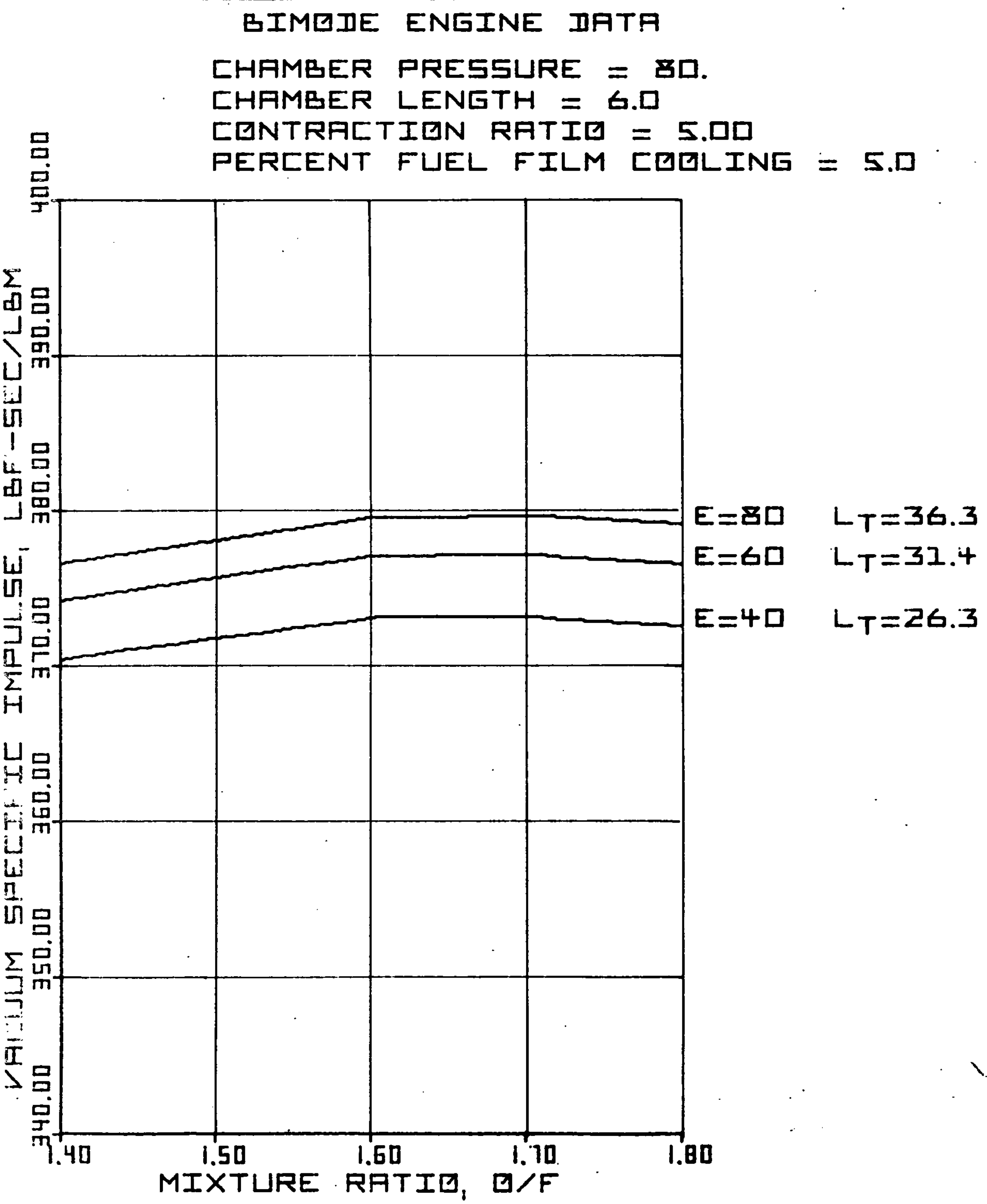
FLUORINE/HYDRAZINE ENGINE STUDY



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FLUORINE/HYDRAZINE ENGINE STUDY

BIMODE ENGINE DATA

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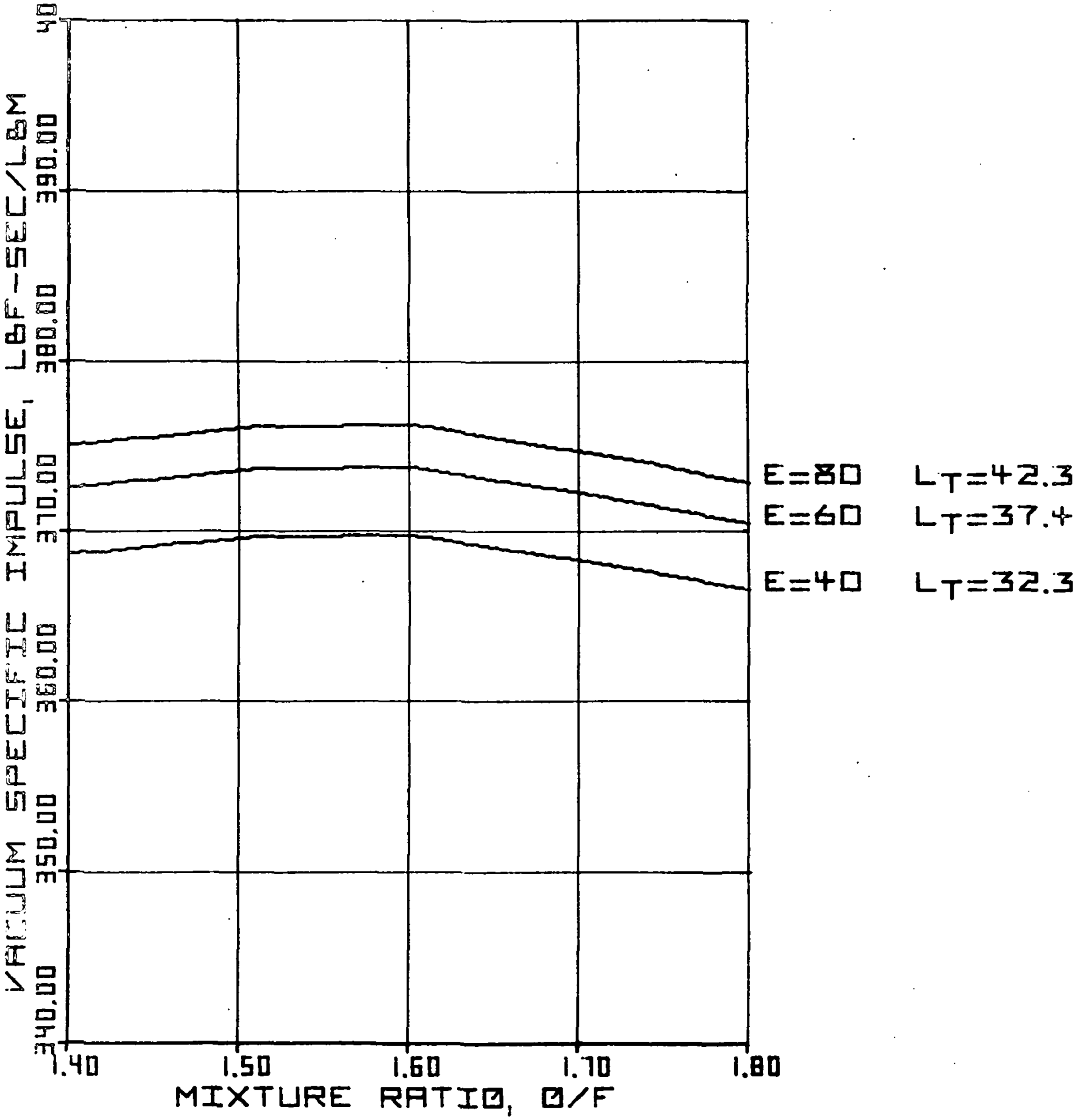
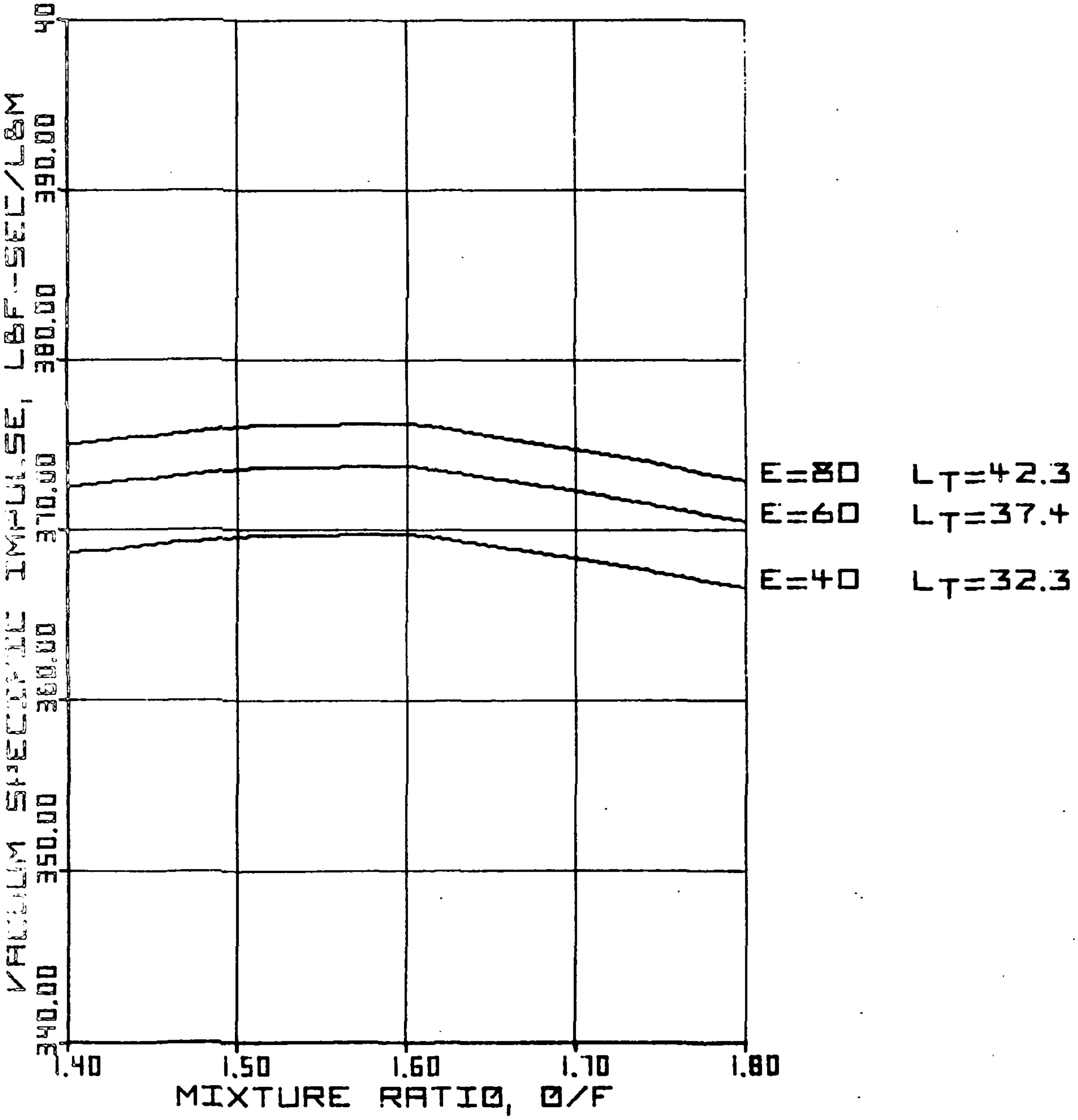
CONTRACTION RATIO = 1.50
PERCENT FUEL FILM COOLING = 13.4



FLUORINE/HYDRAZINE ENGINE STUDY

BIMODE ENGINE DATA

CHAMBER PRESSURE = 80.
CHAMBER LENGTH = 12.0
CONTRACTION RATIO = 2.50
PERCENT FUEL FILM COOLING = 13.4



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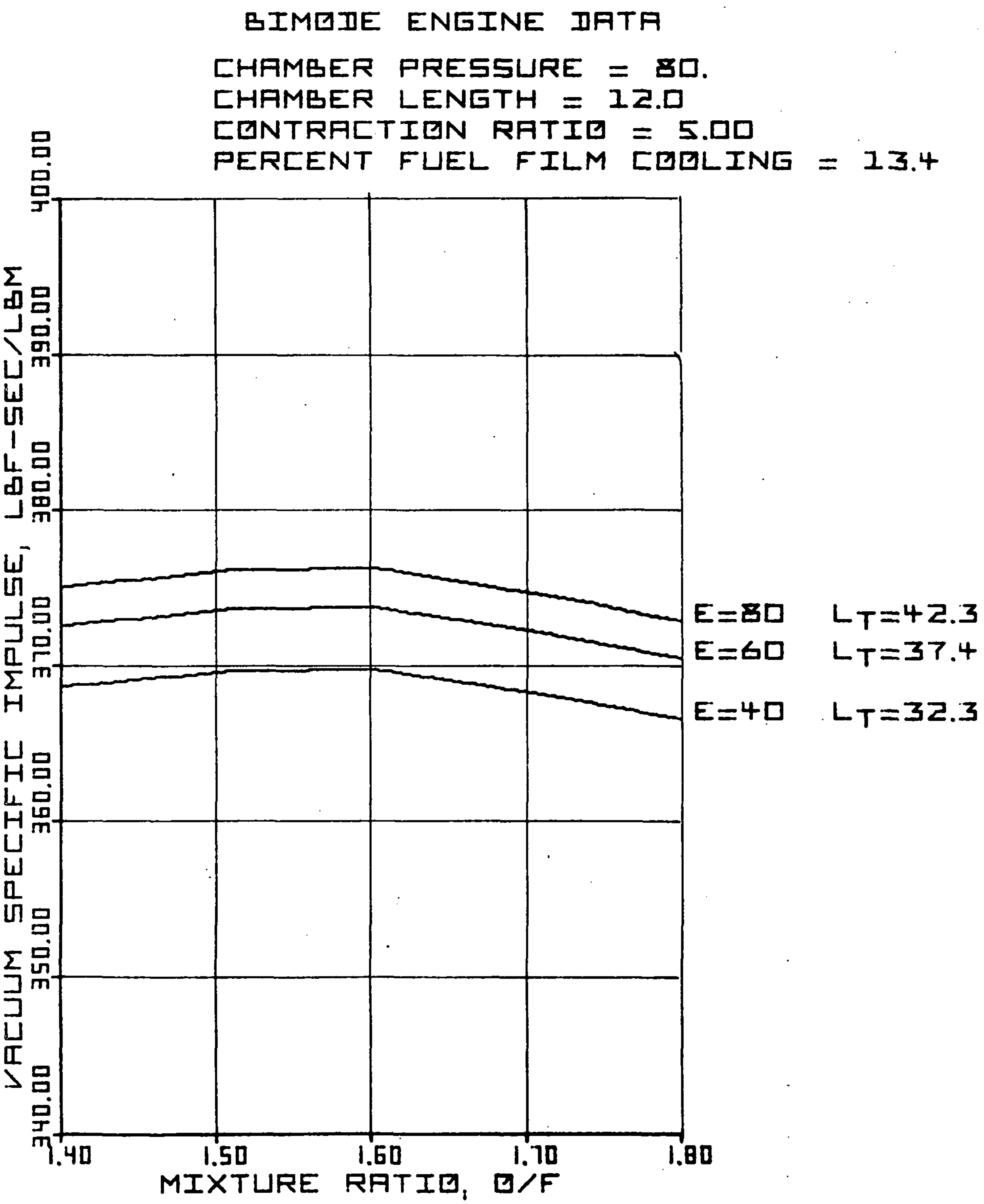

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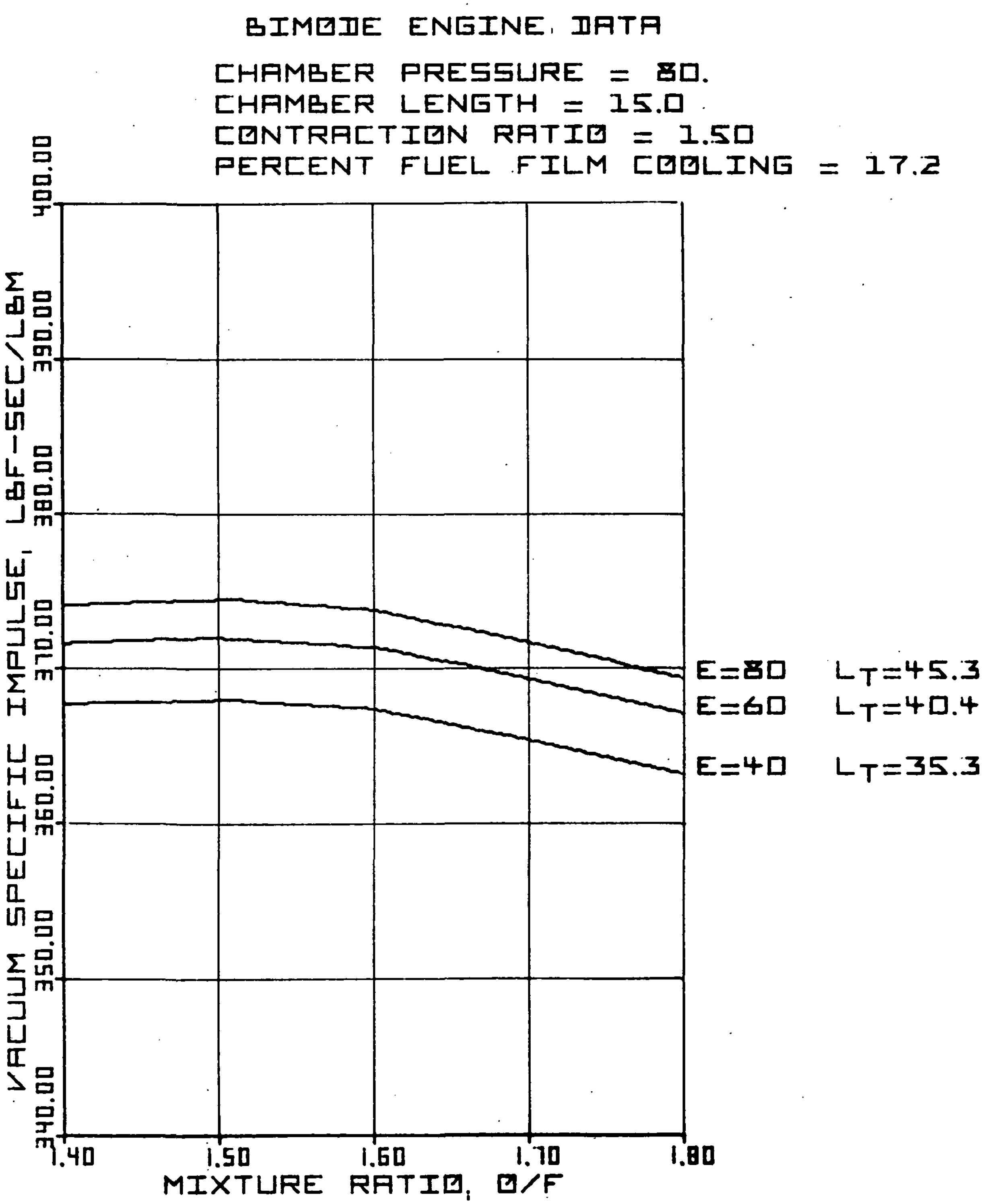

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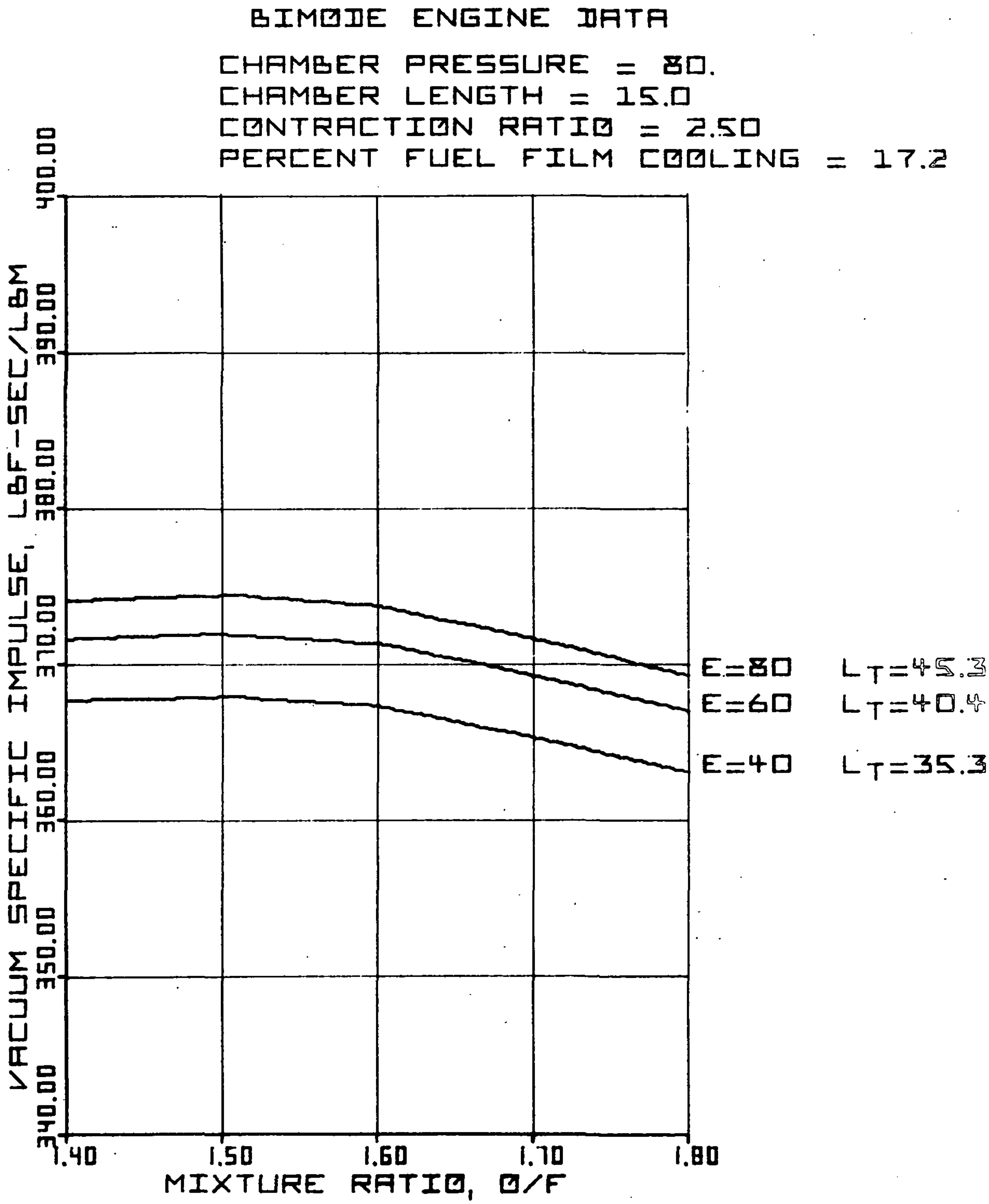

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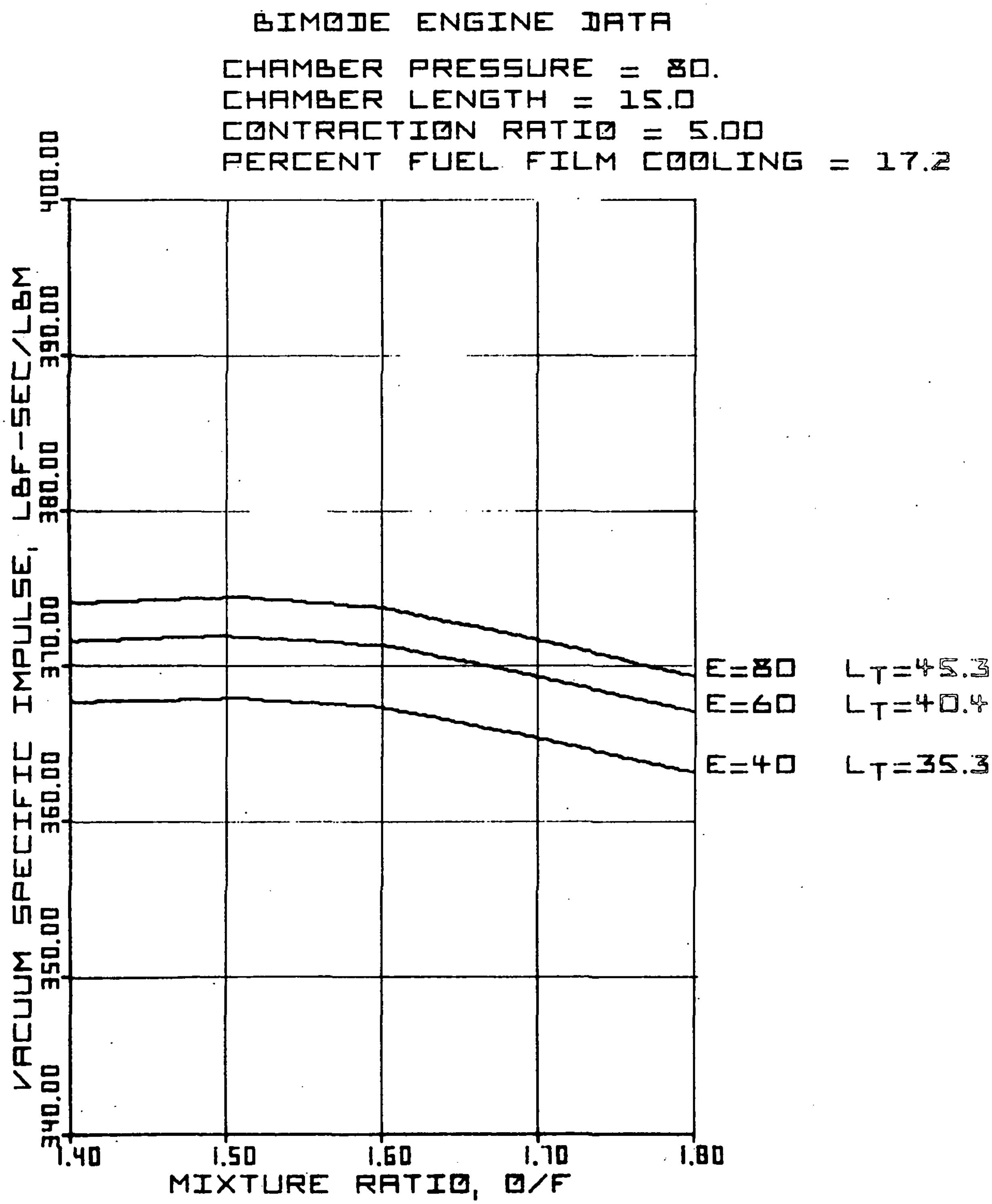

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FLUORINE/HYDRAZINE ENGINE STUDY

BIMODE ENGINE DATA

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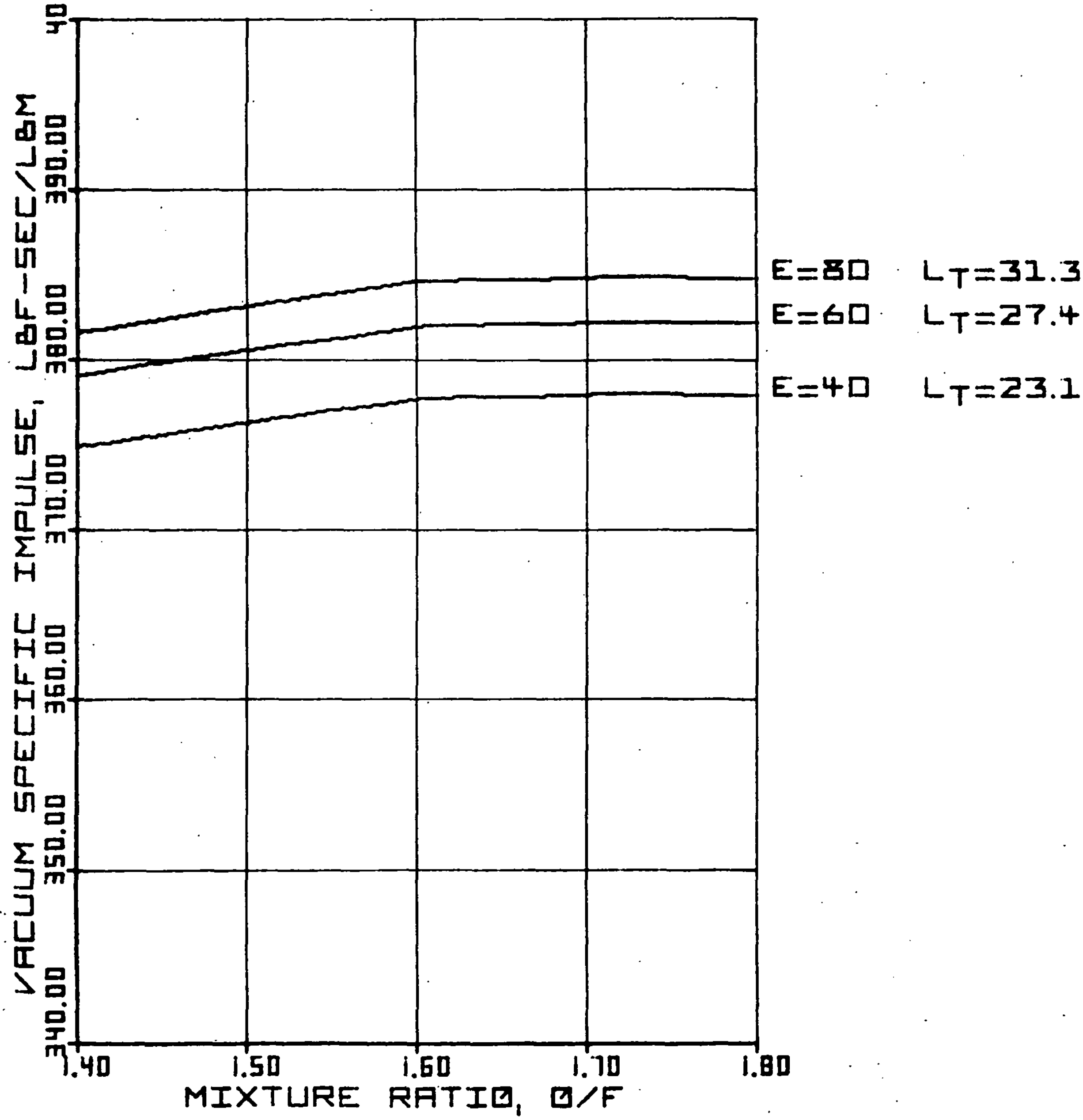
CONTRACTION RATIO = 1.50
PERCENT FUEL FILM COOLING = 5.0



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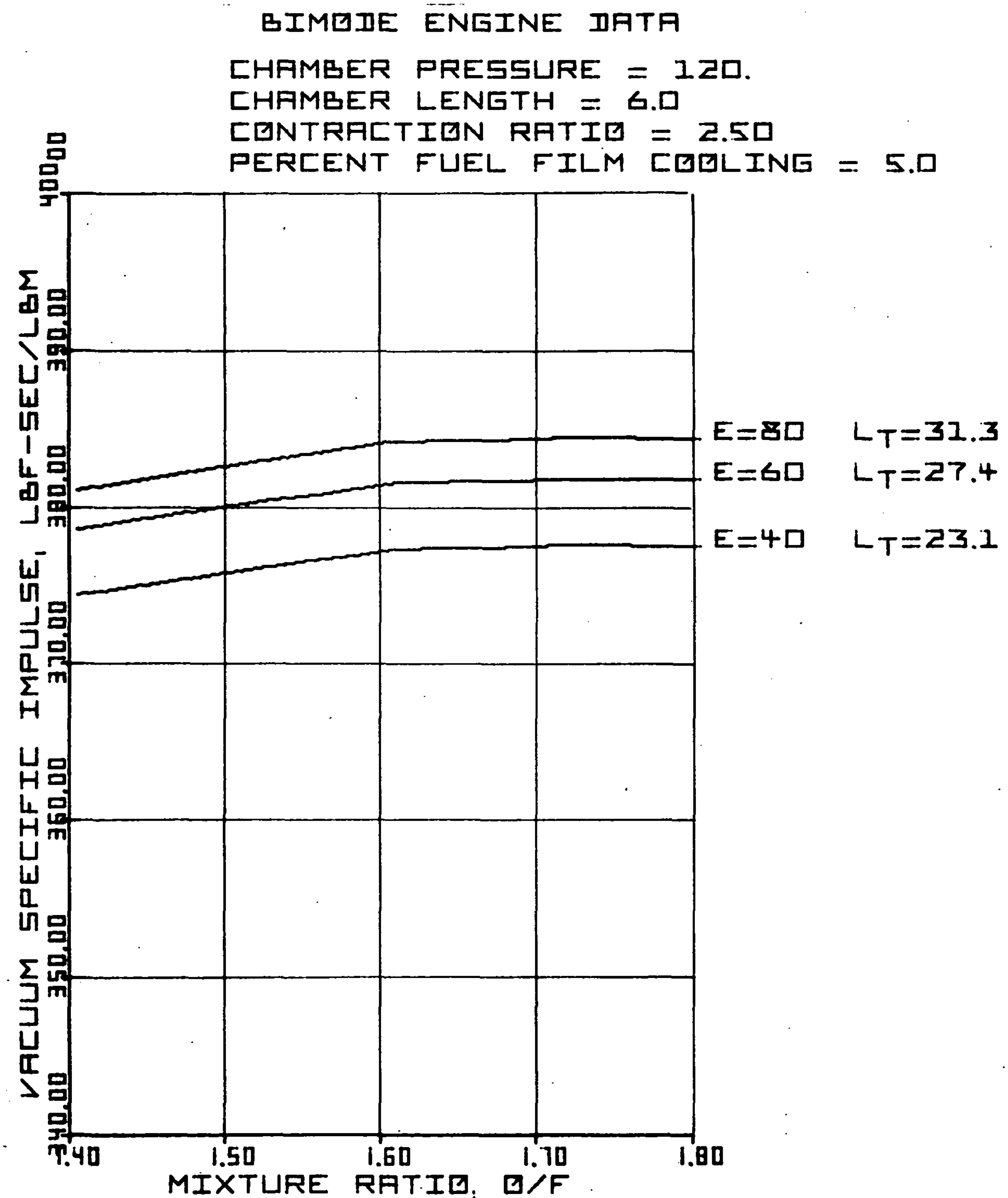

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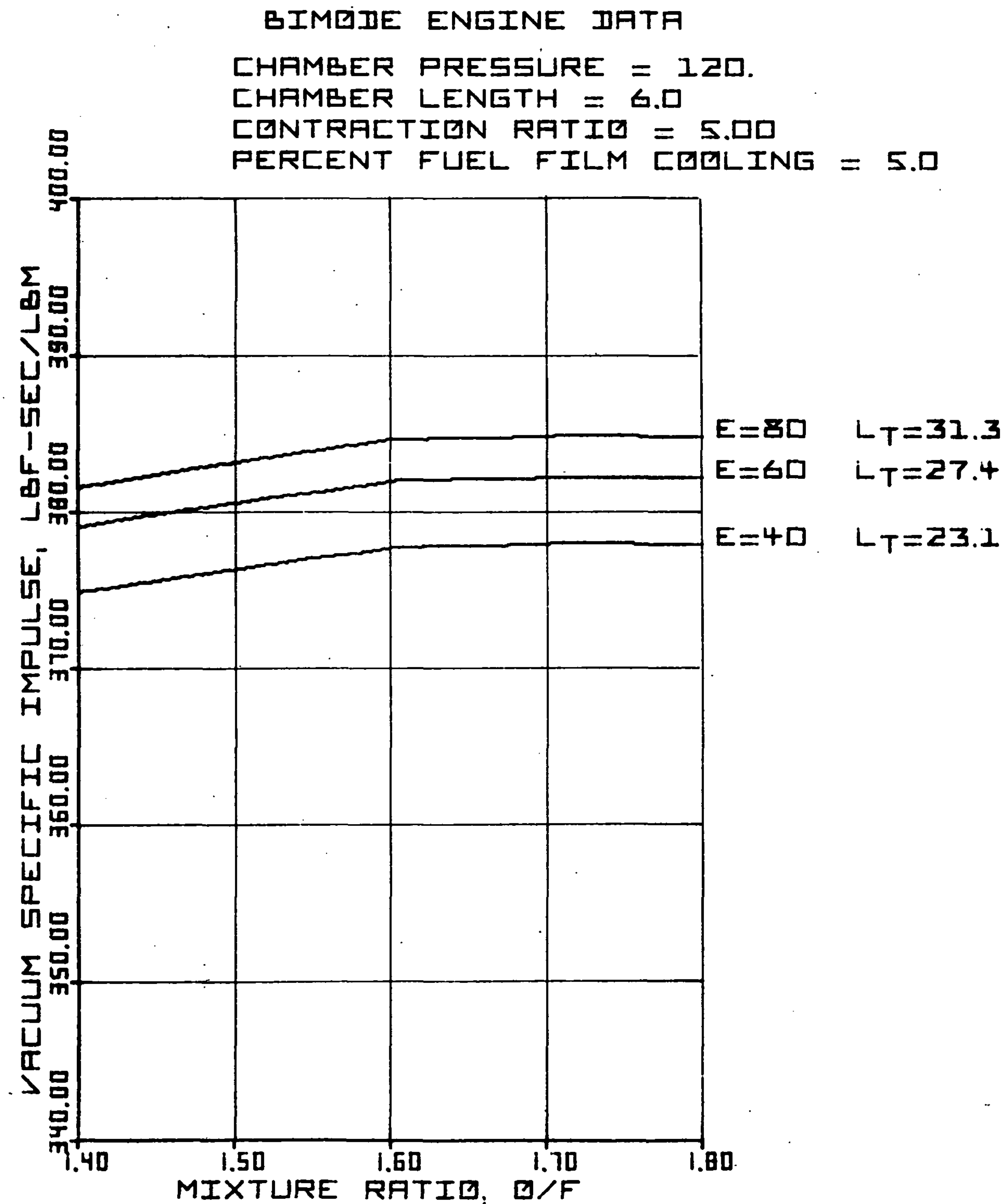

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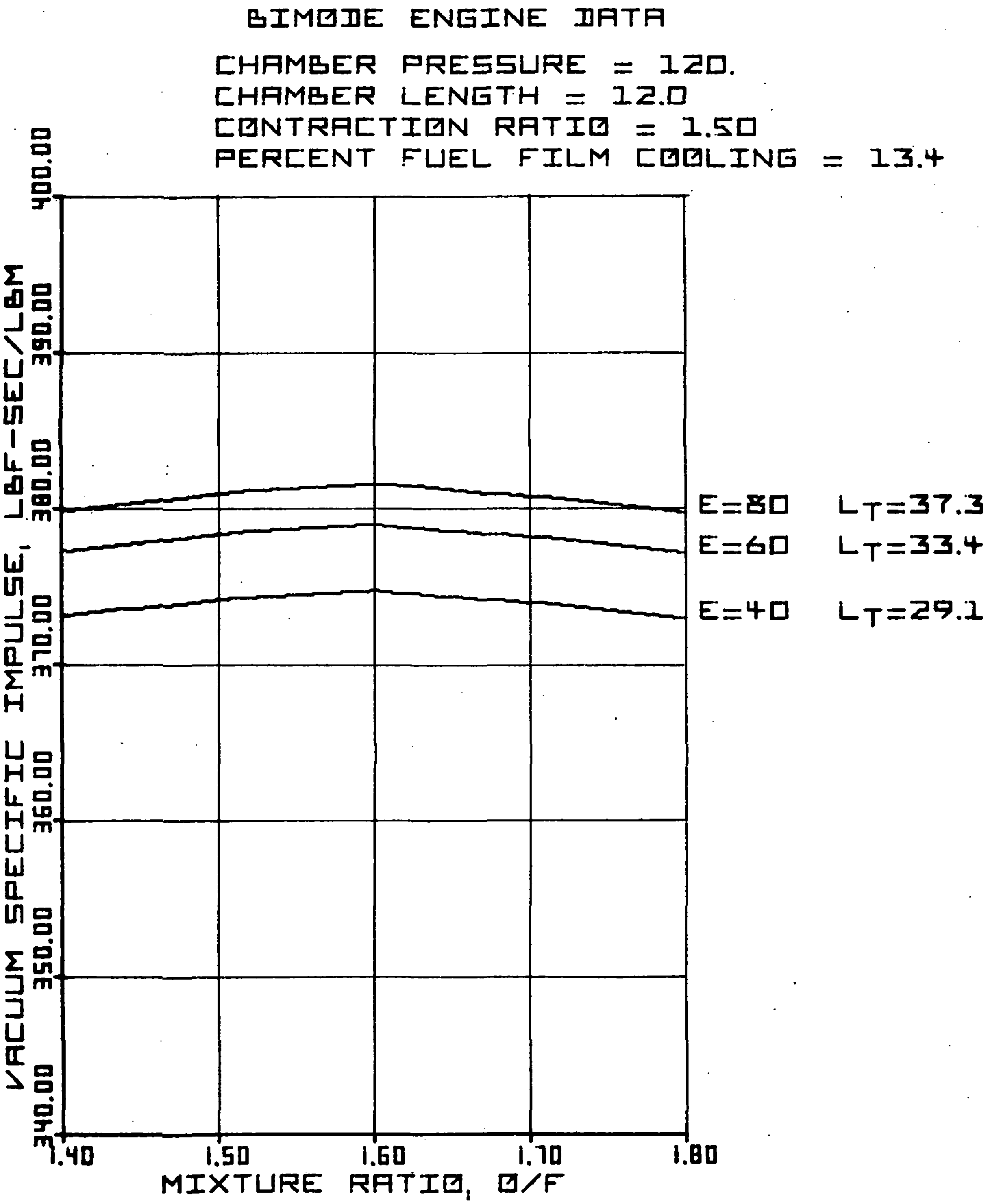

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FLUORINE/HYDRAZINE ENGINE STUDY

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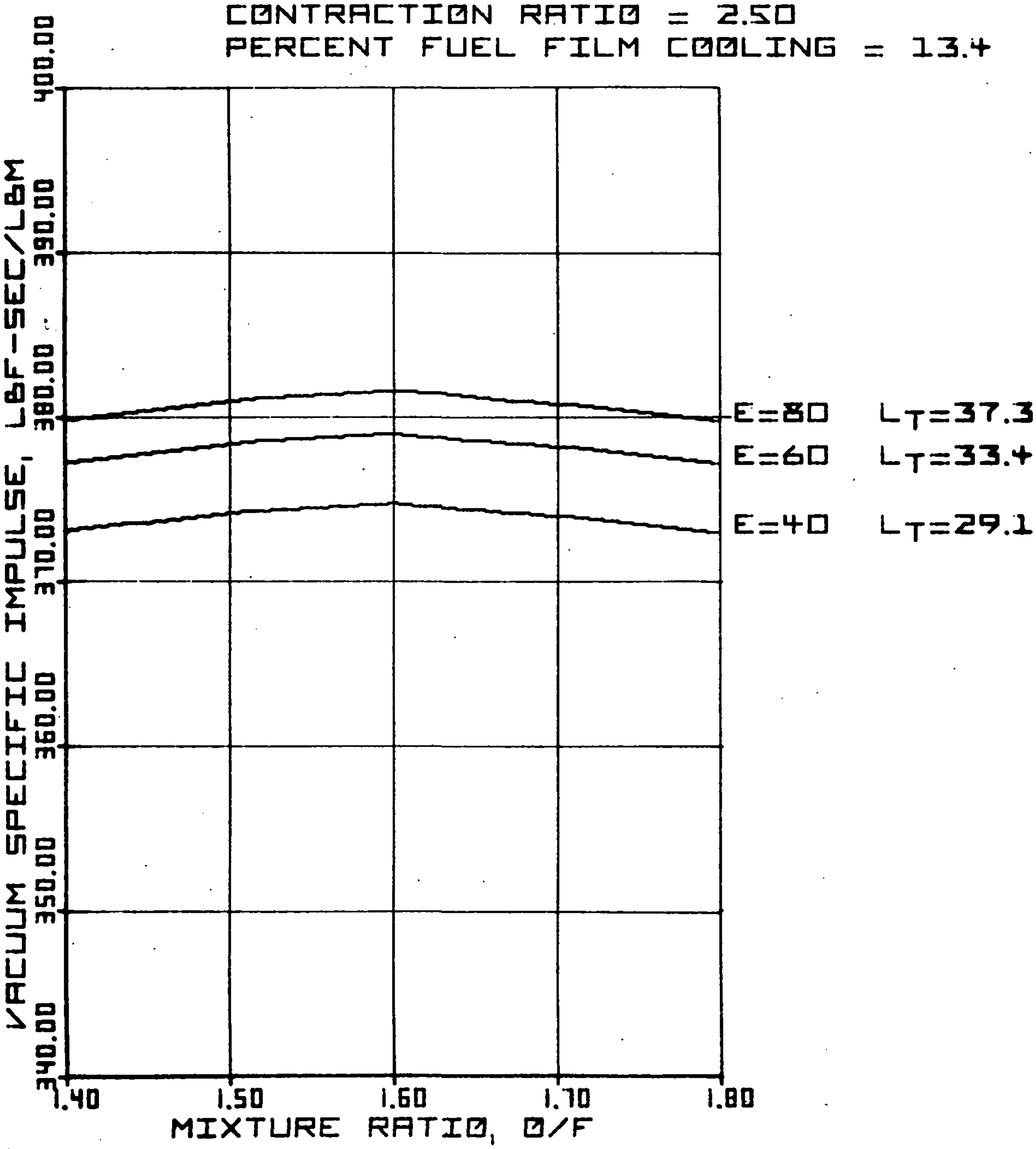
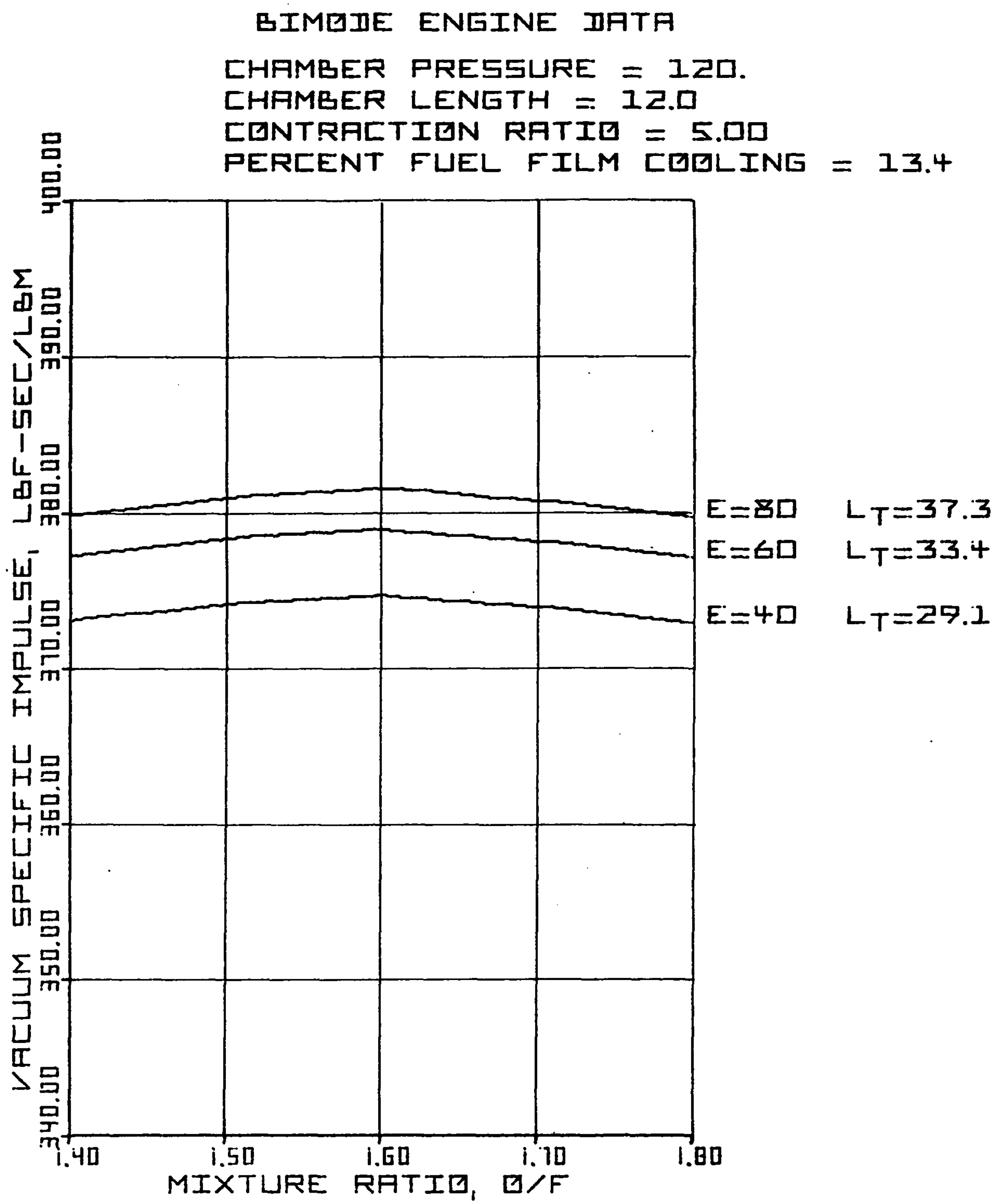
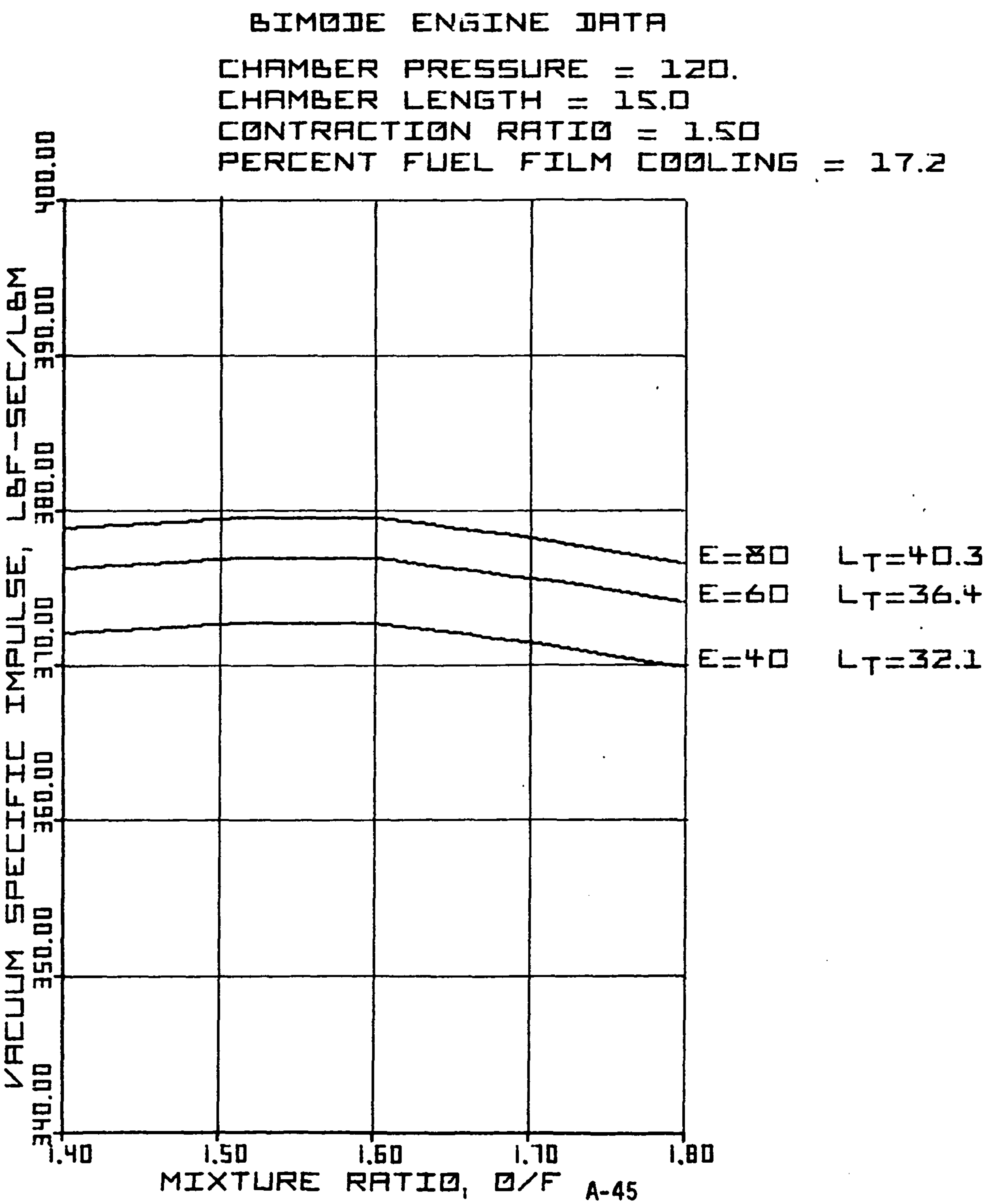
PERCENT FUEL FILM COOLING = 13.4



FLUORINE/HYDRAZINE
ENGINE STUDY



FLUORINE/HYDRAZINE
ENGINE STUDY



FLUORINE/HYDRAZINE
ENGINE STUDY

BIMODE ENGINE DATA

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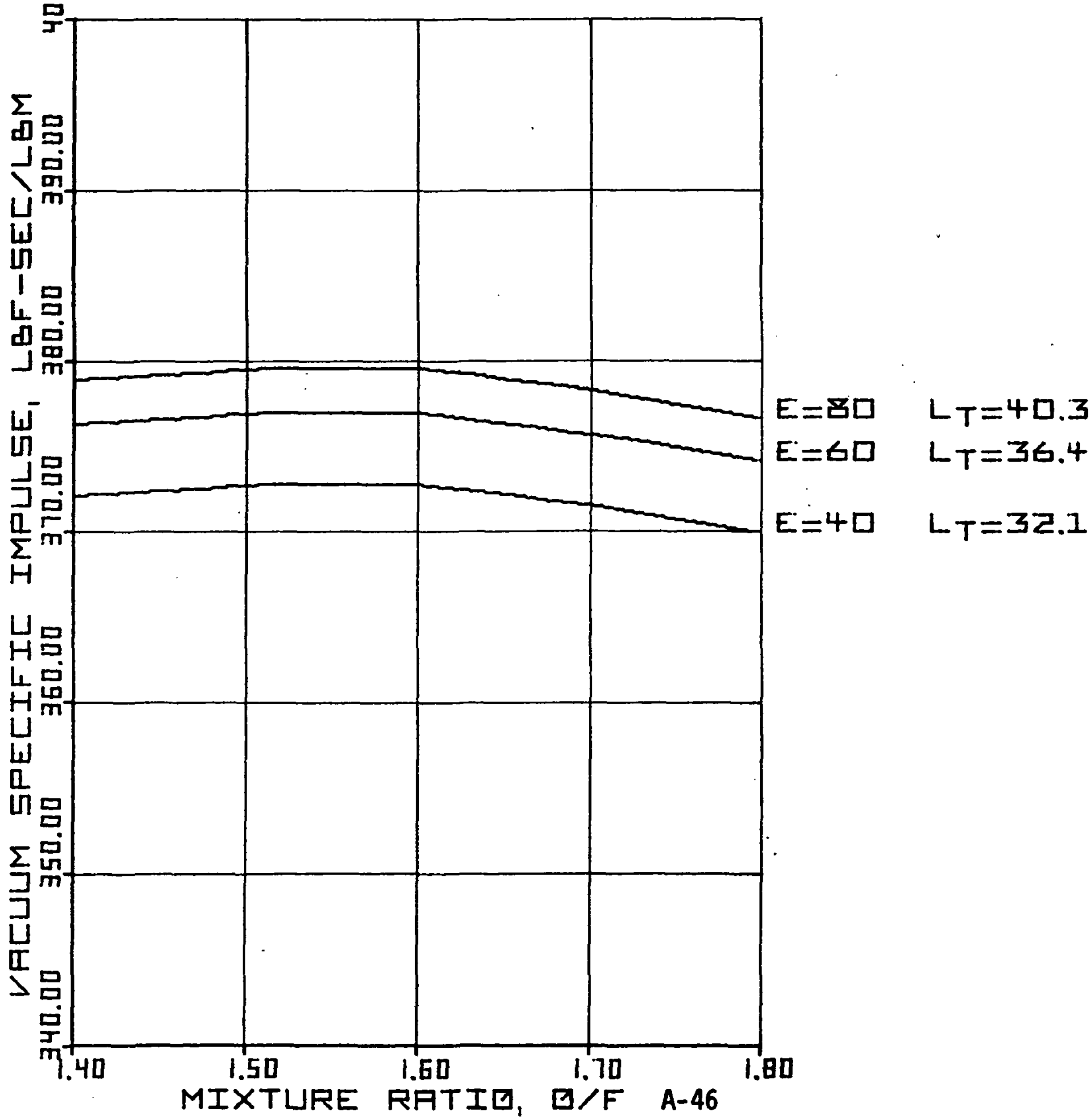
CHAMBER LENGTH = 15.0
CONTRACTION RATIO = 2.50
PERCENT FUEL FILM COOLING = 17.2



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FLUORINE/HYDRAZINE ENGINE STUDY

BIMODE ENGINE DATA

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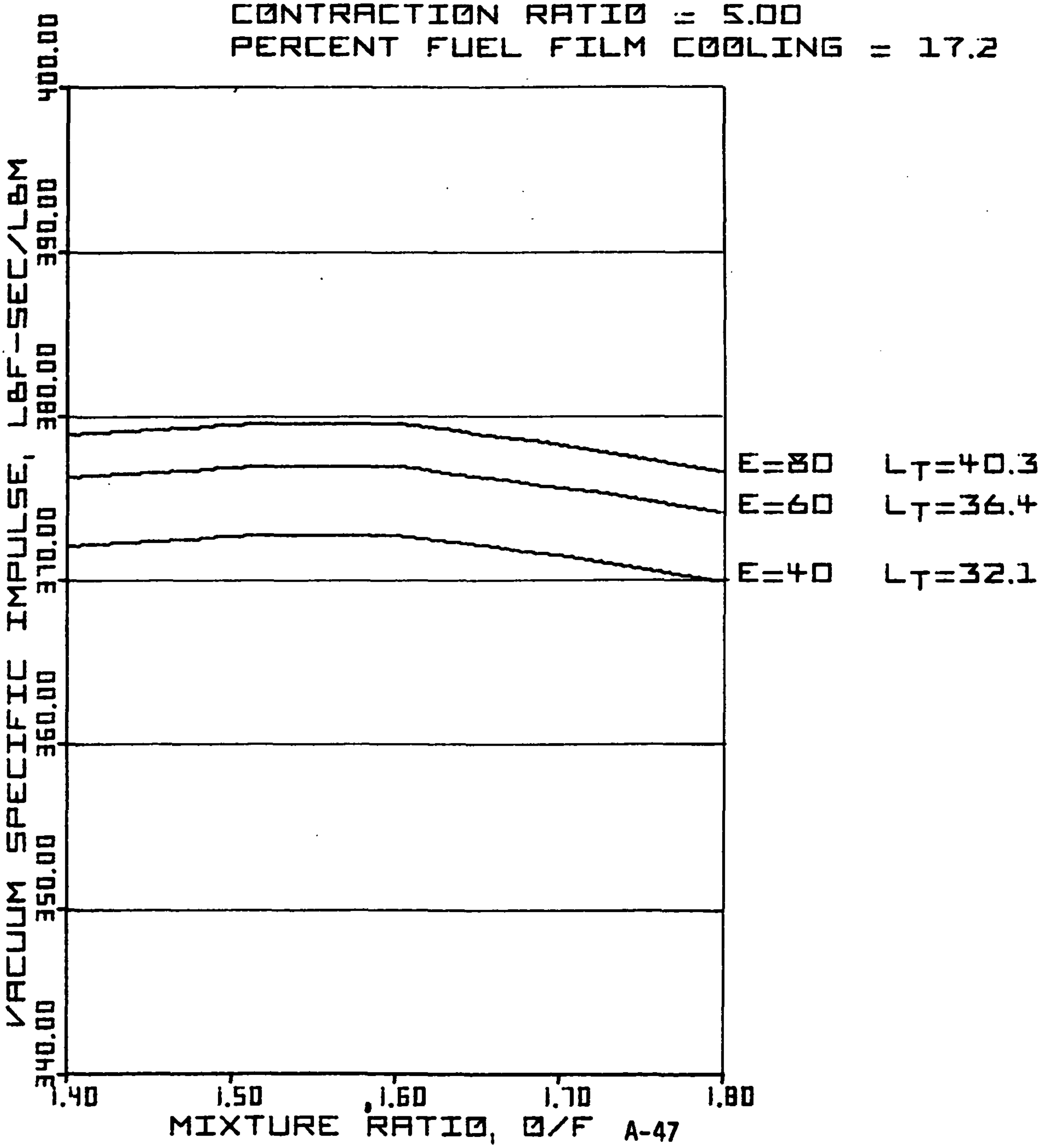
PERCENT FUEL FILM COOLING = 17.2



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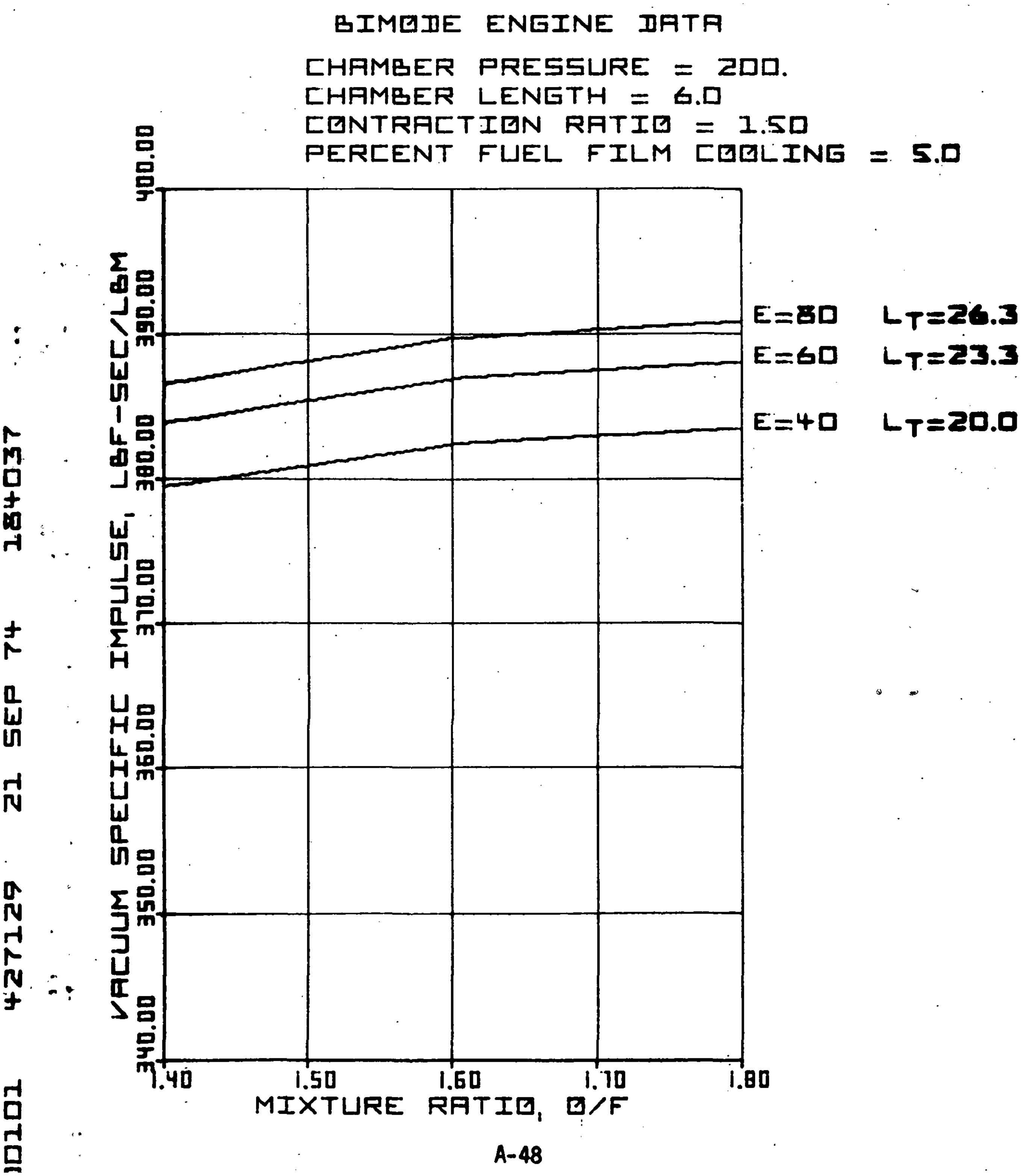

FLUORINE/HYDRAZINE ENGINE STUDY

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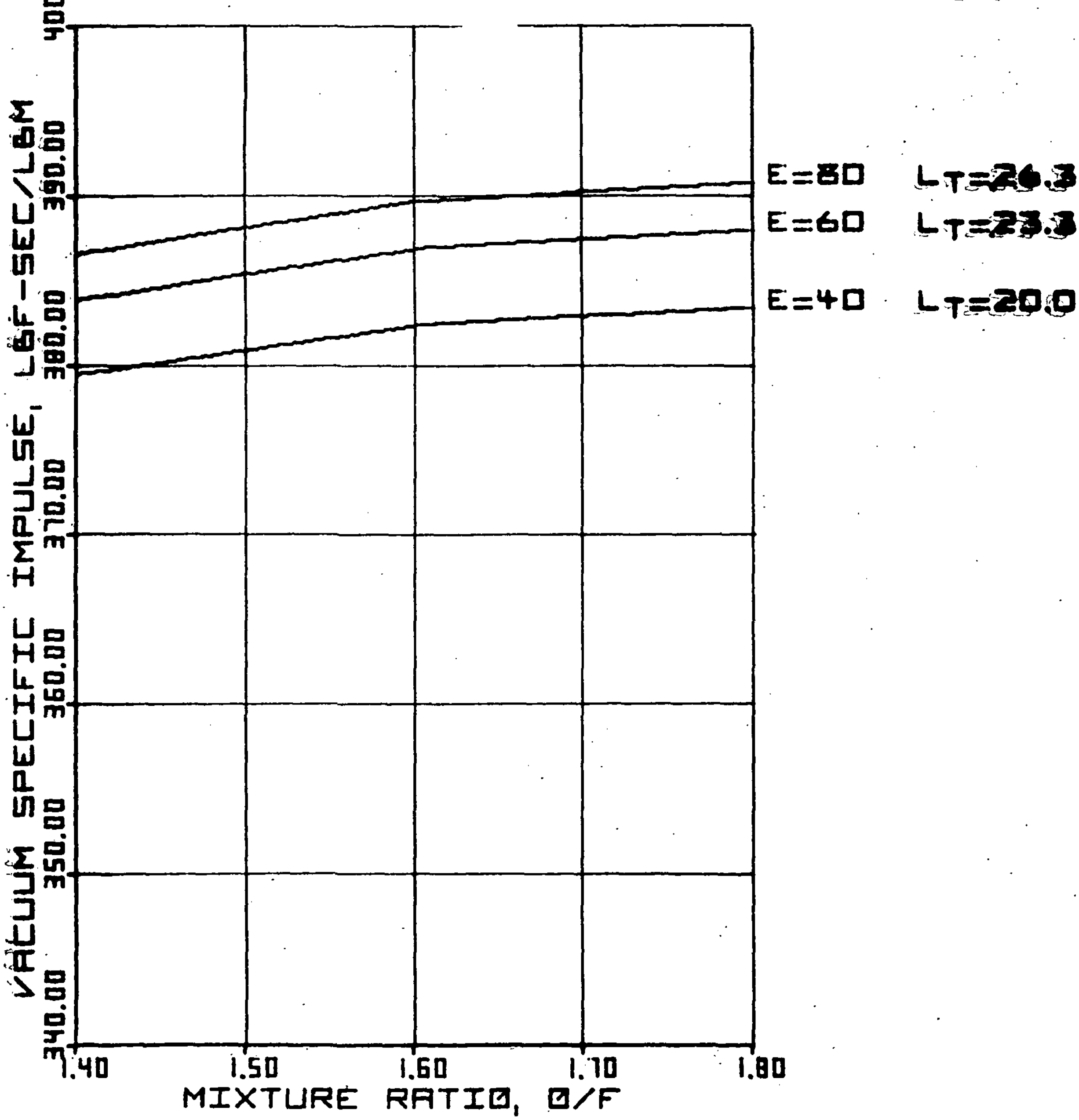
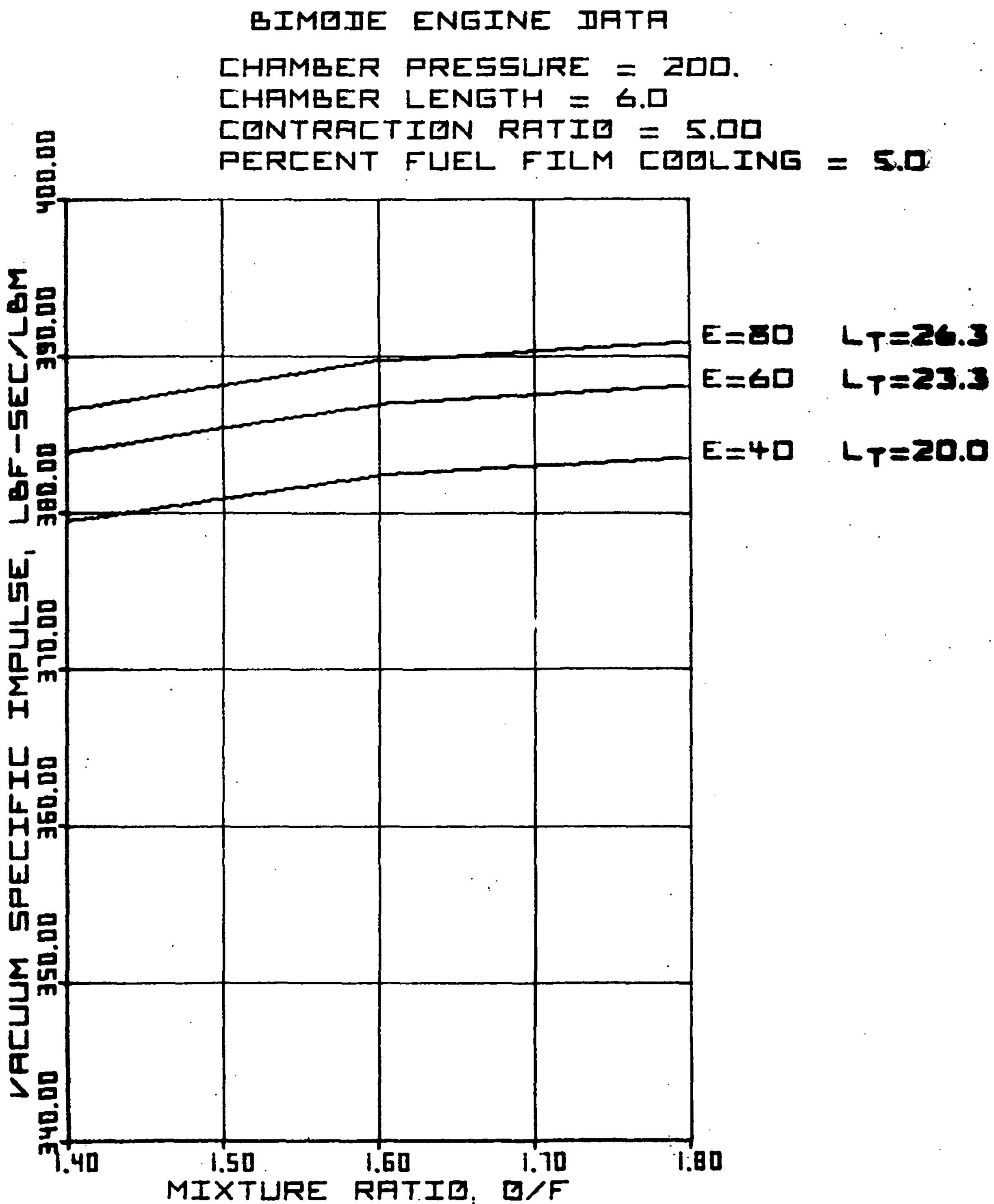
PERCENT FUEL FILM COOLING = 5.0



FLUORINE/HYDRAZINE ENGINE STUDY



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FLUORINE/HYDRAZINE ENGINE STUDY

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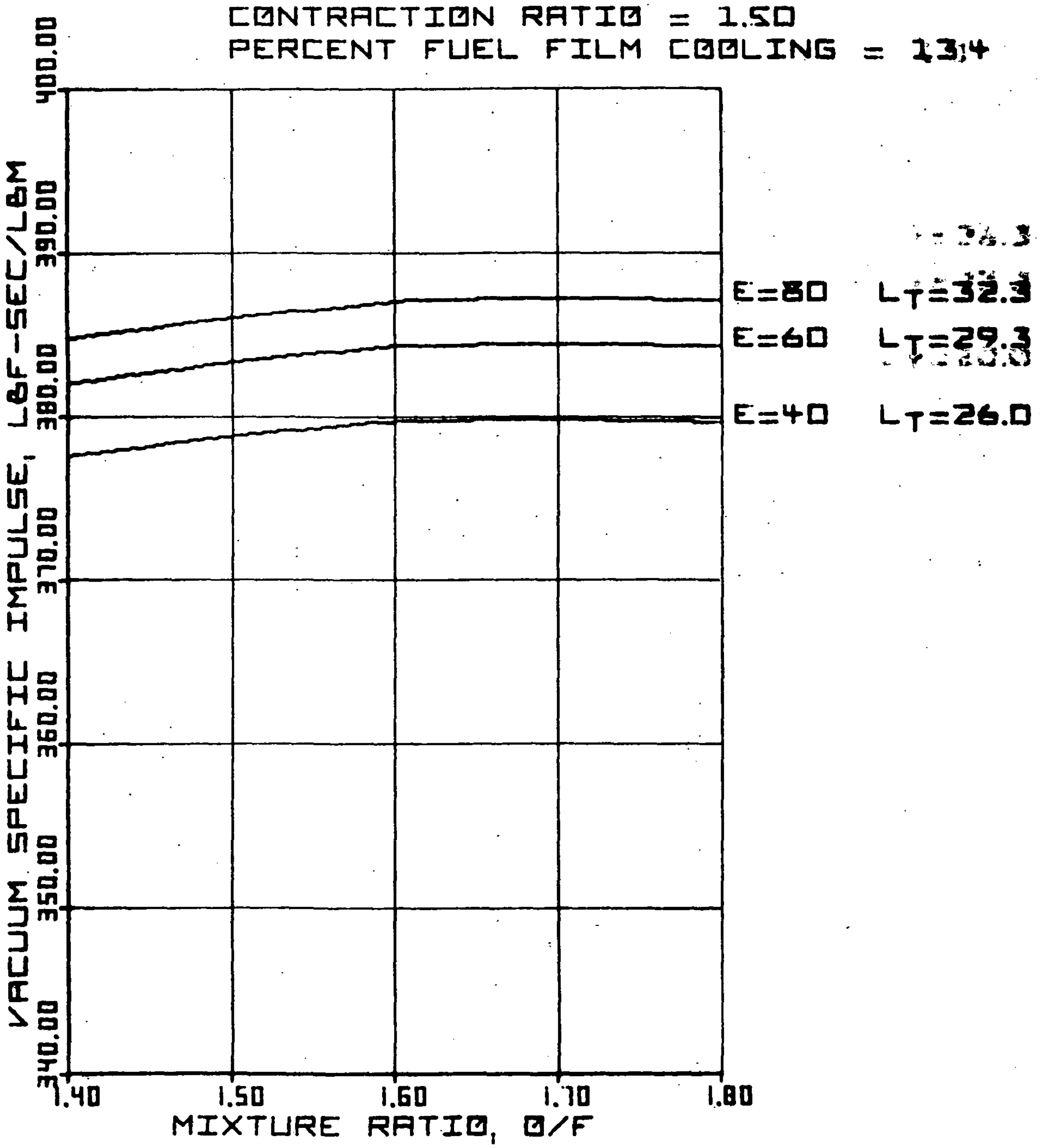

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FLUORINE/HYDRAZINE ENGINE STUDY

BIMODE ENGINE DATA

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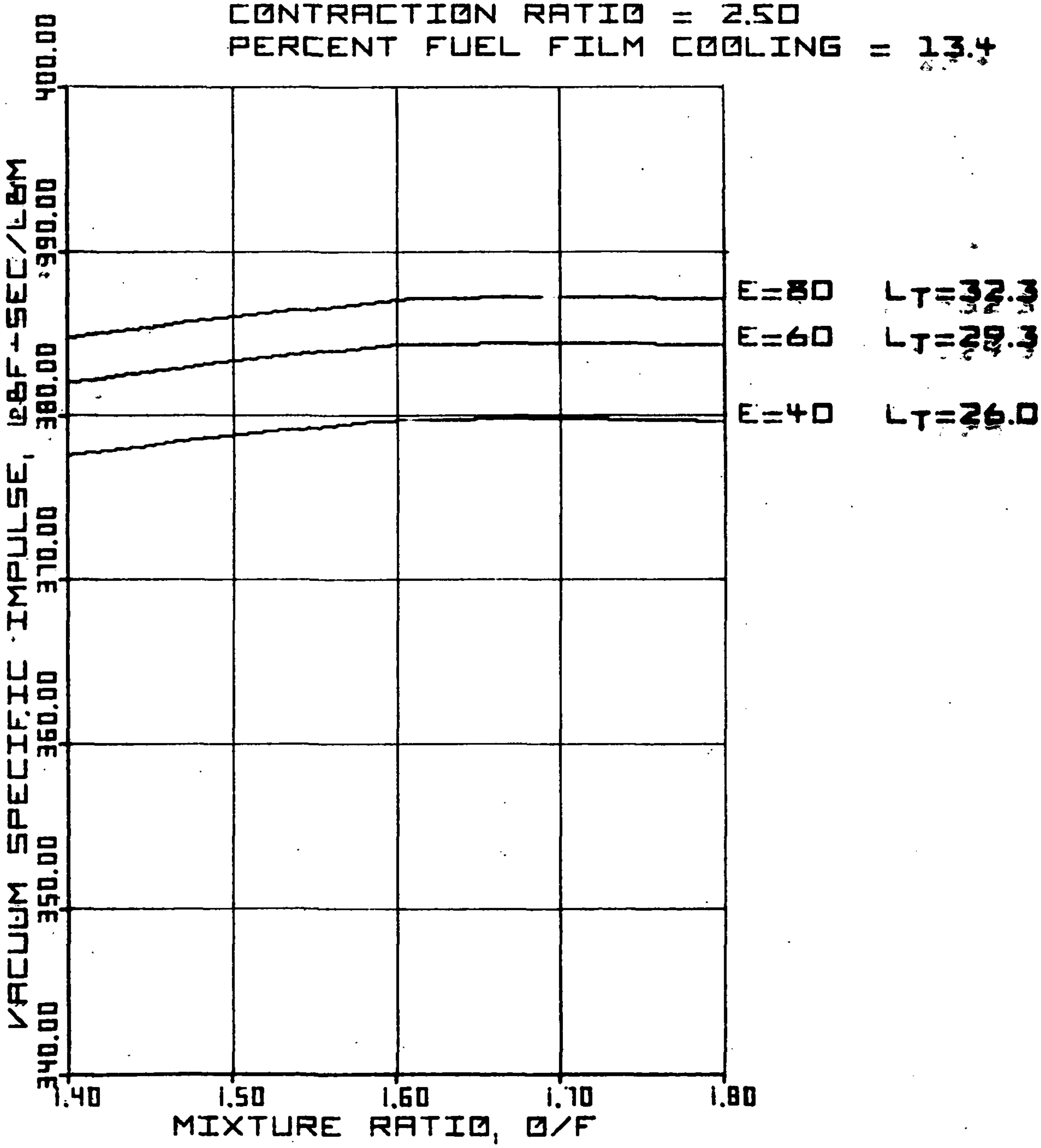
CONTRACTION RATIO = 2.50
PERCENT FUEL FILM COOLING = 13.4



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FLUORINE/HYDRAZINE ENGINE STUDY

BIMODE ENGINE DATA

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CHAMBER LENGTH = 12.0
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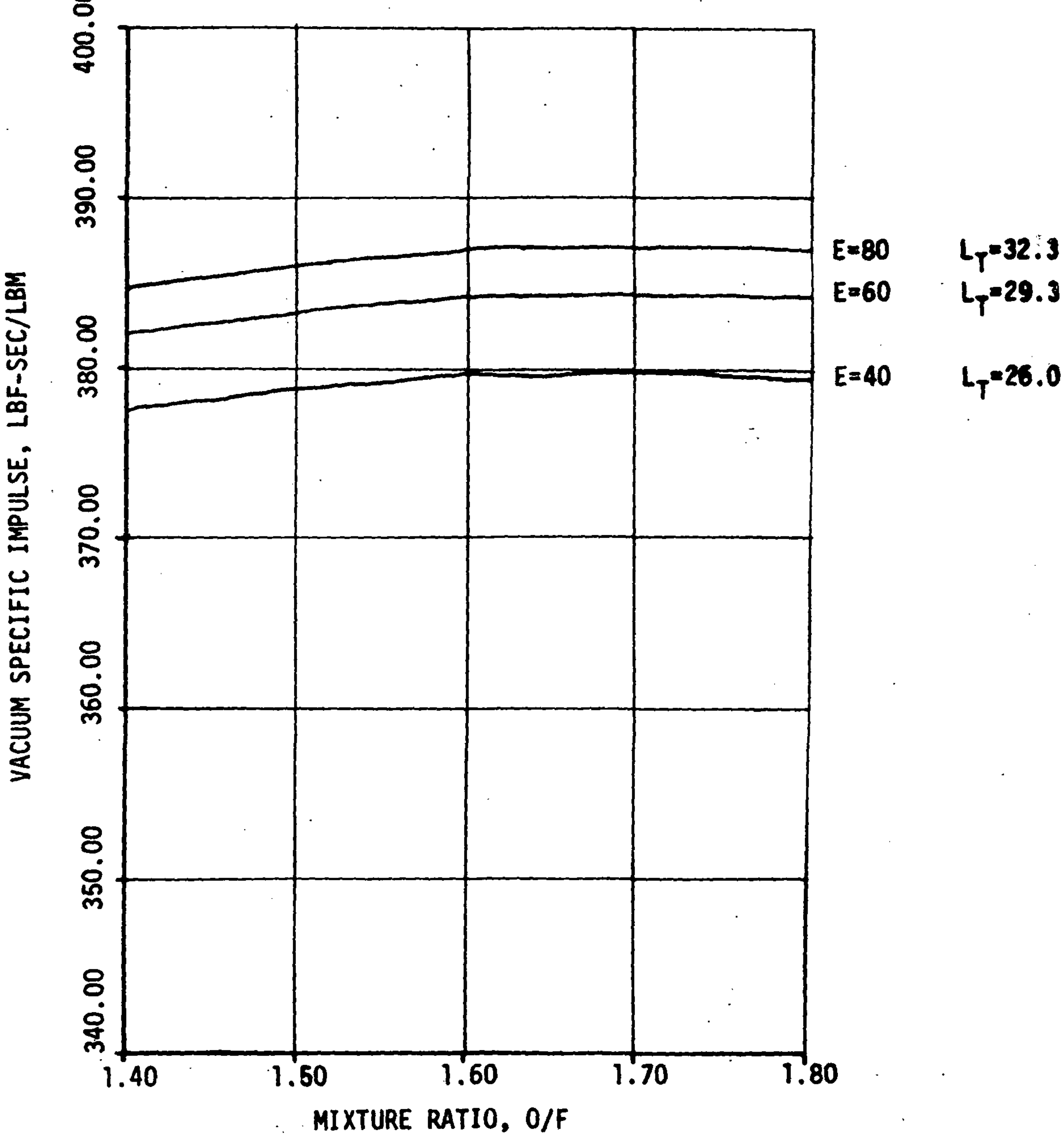
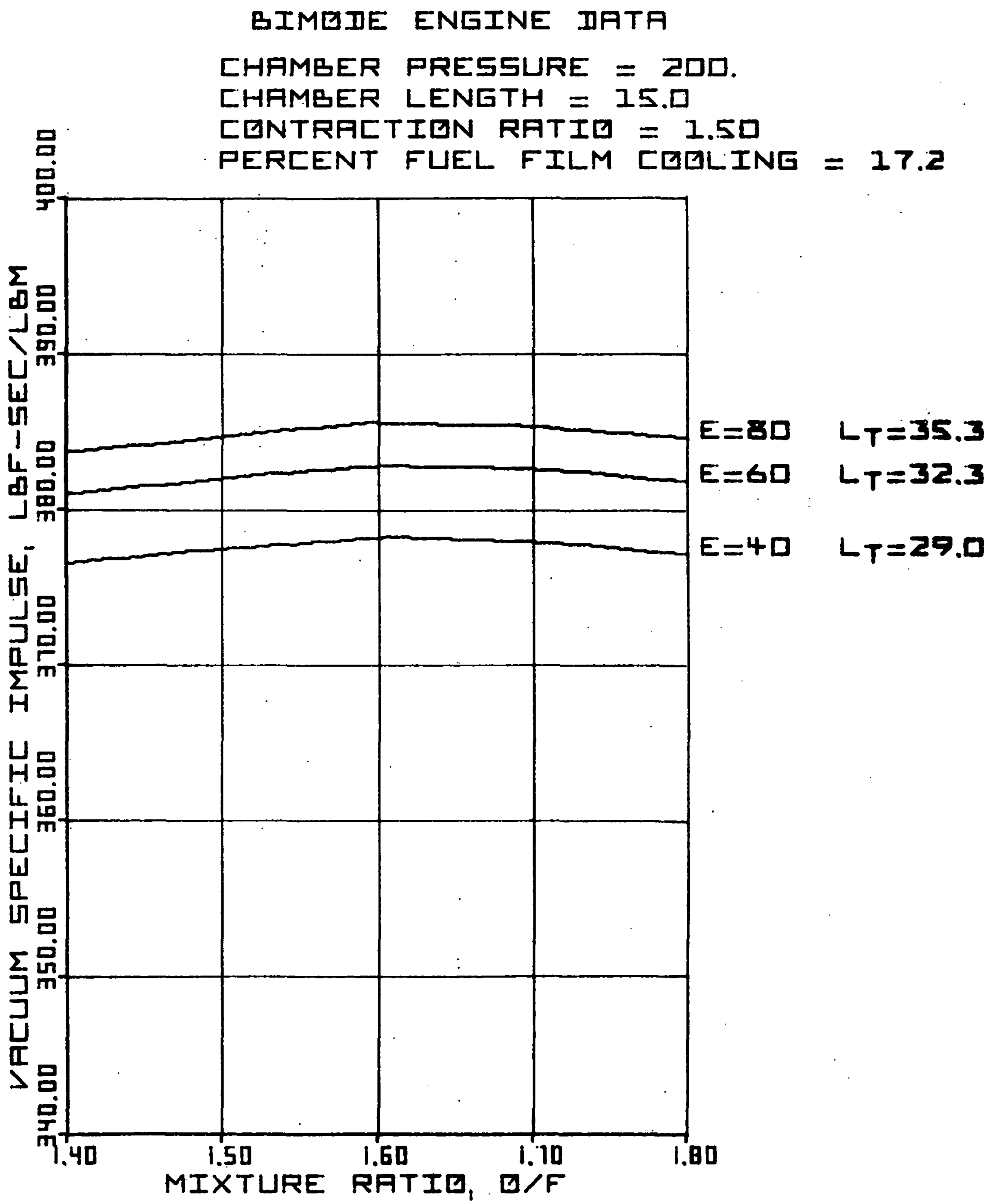
PERCENT FUEL FILM COOLING = 13.4



FLUORINE/HYDRAZINE ENGINE STUDY



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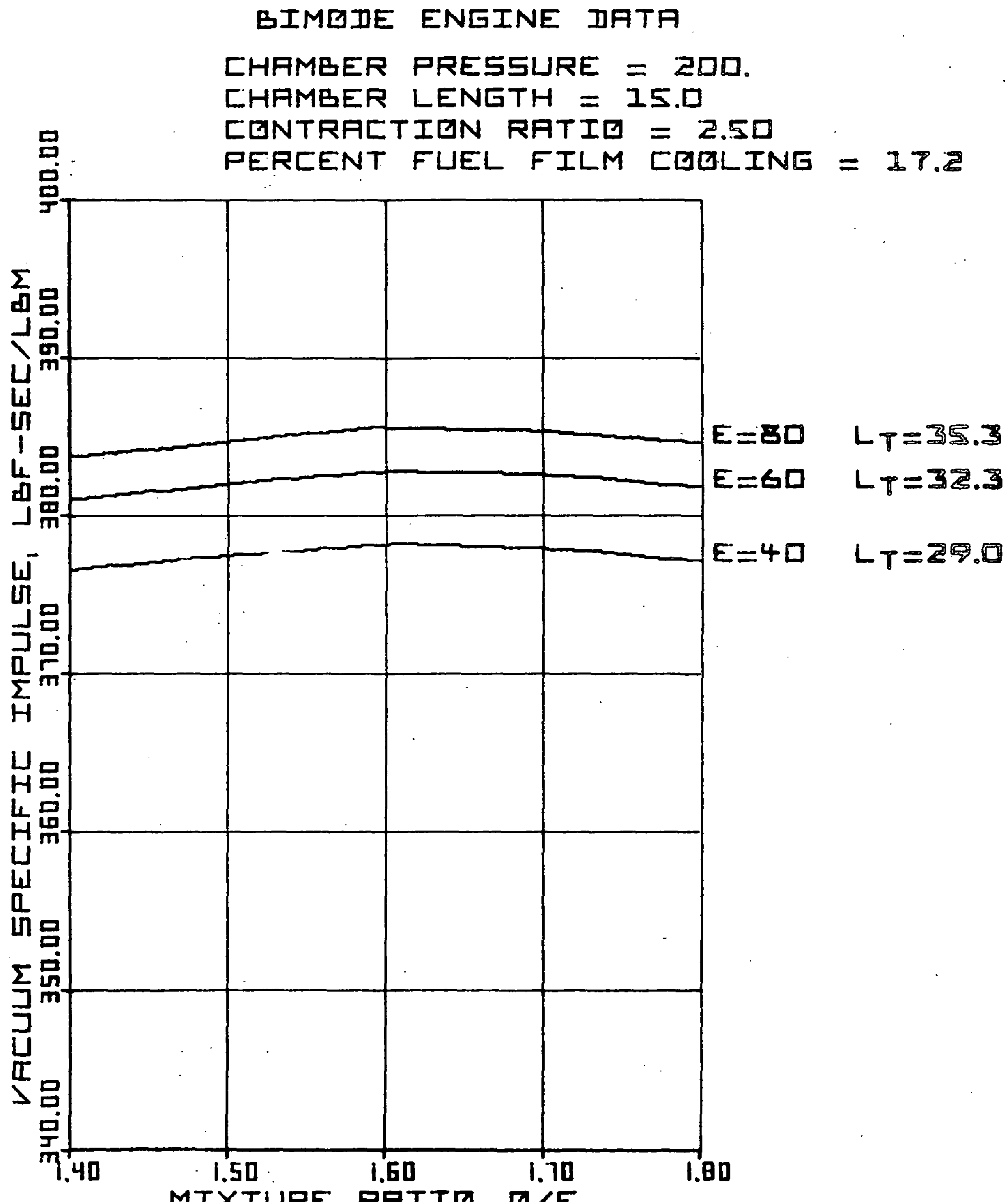
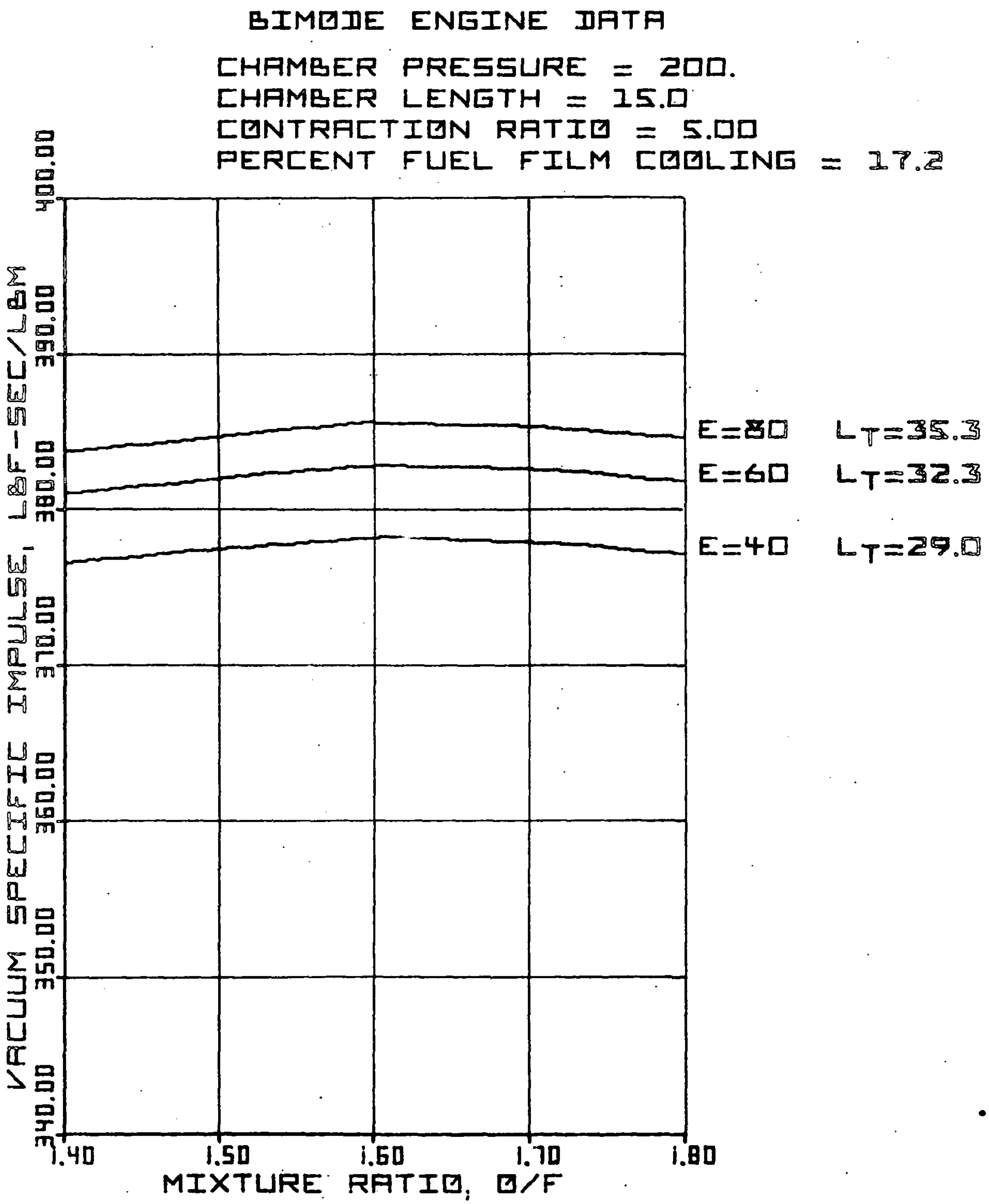


FLUORINE/HYDRAZINE
ENGINE STUDY

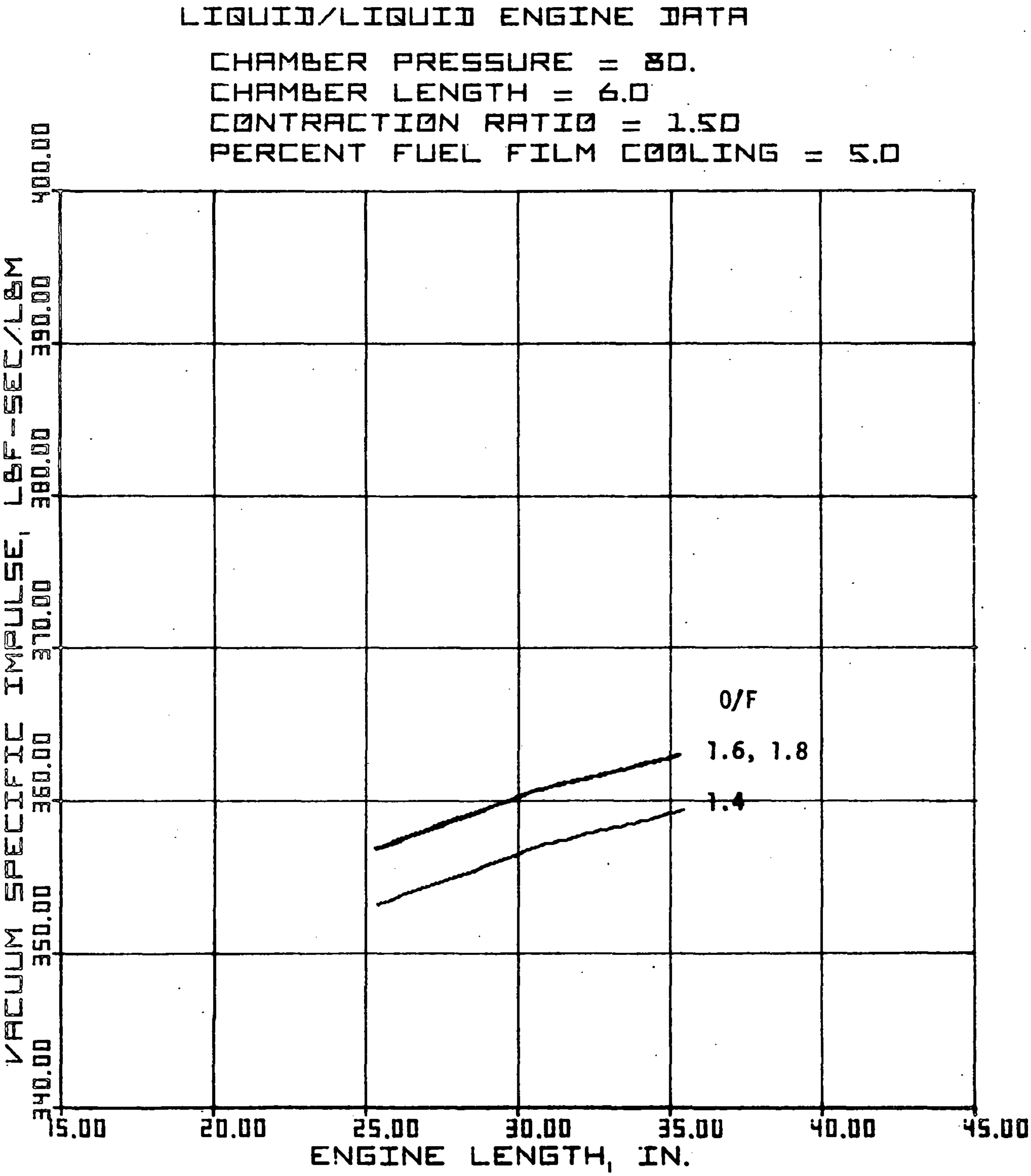


APPENDIX A

FIGURE SET C

LIQUID-LIQUID ENGINE SPECIFIC IMPULSE VERSUS ENGINE LENGTH

FLUORINE/HYDRAZINE ENGINE STUDY



FLUORINE/HYDRAZINE ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

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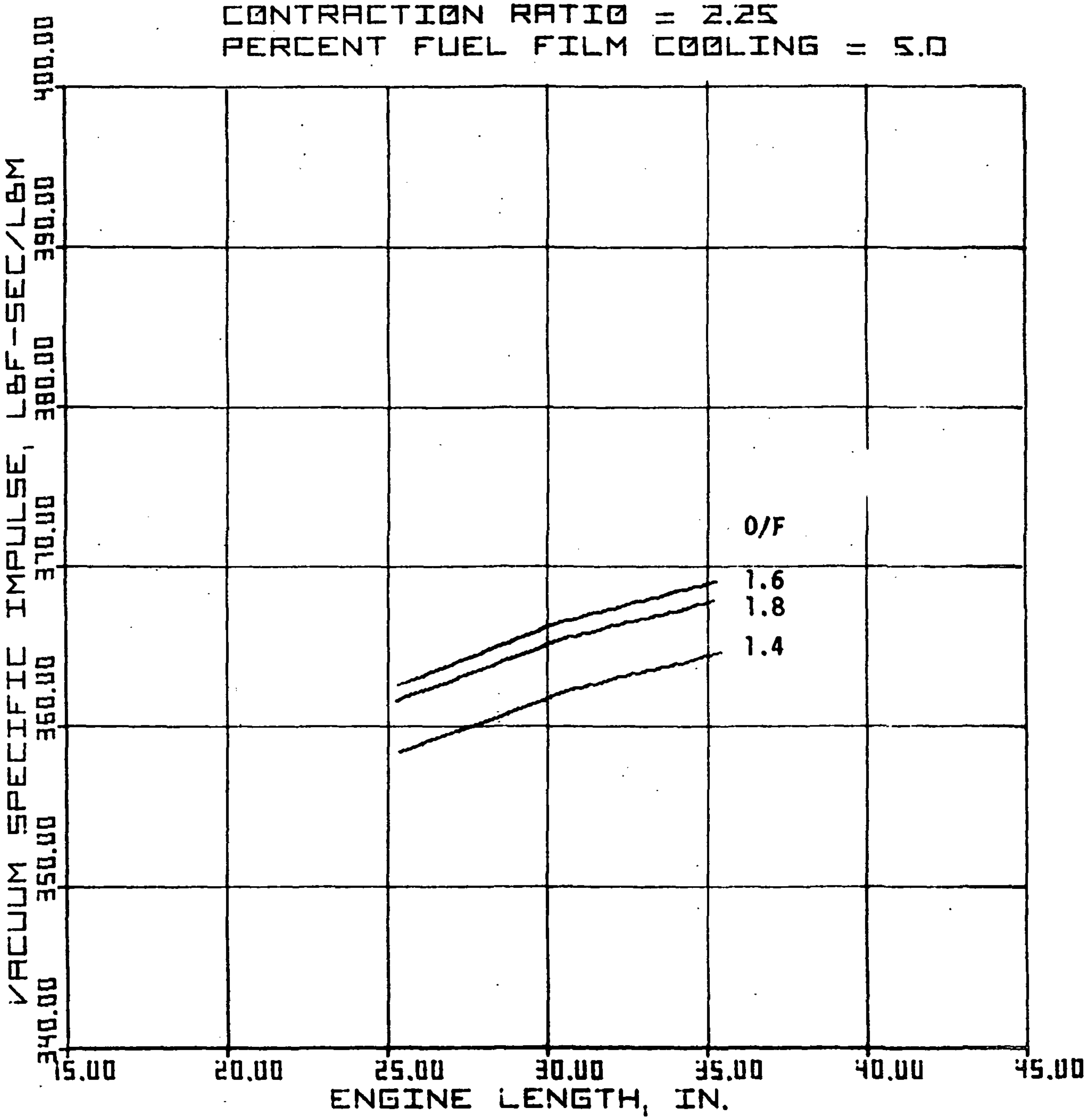
CONTRACTION RATIO = 2.25
PERCENT FUEL FILM COOLING = 5.0



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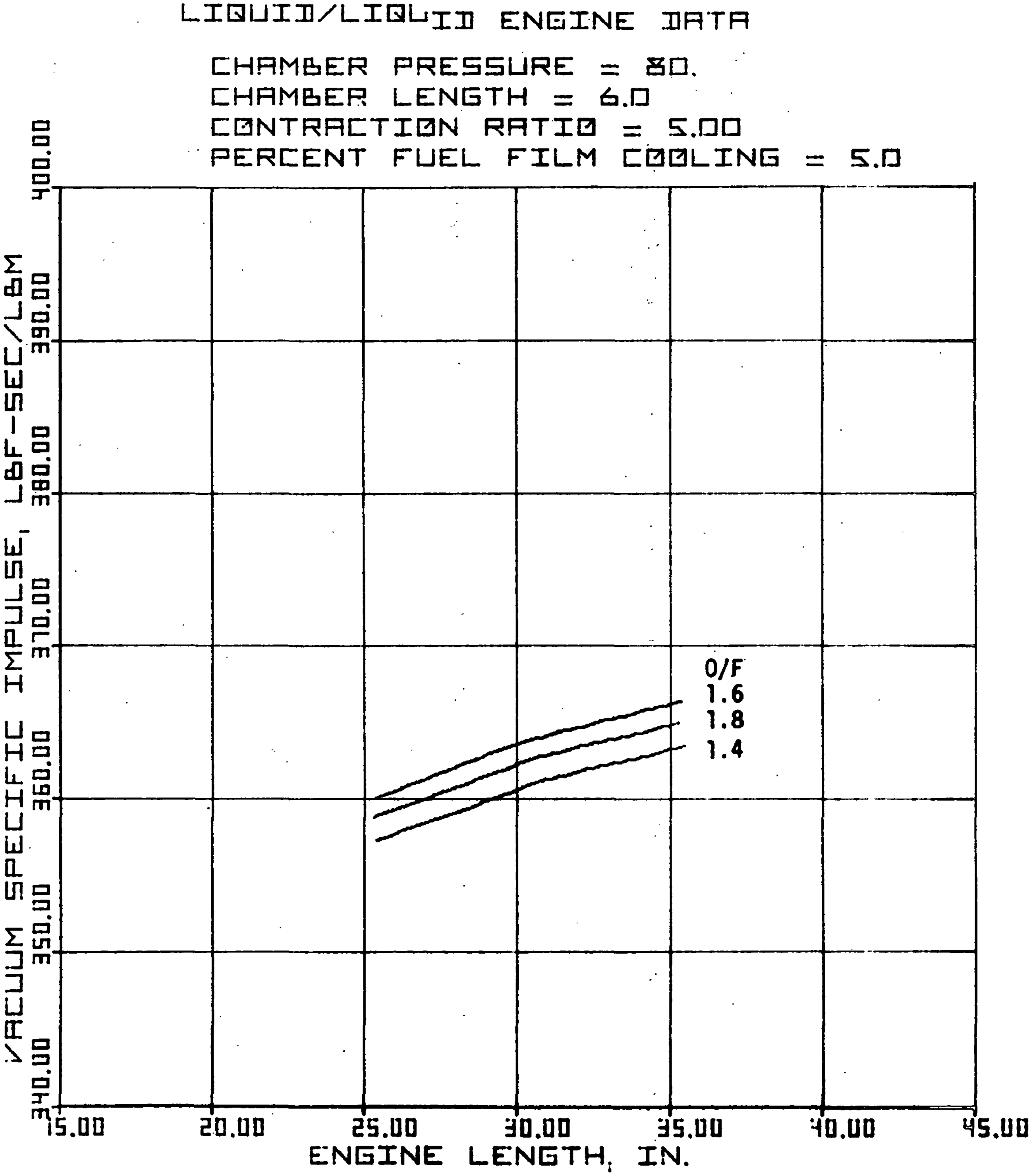
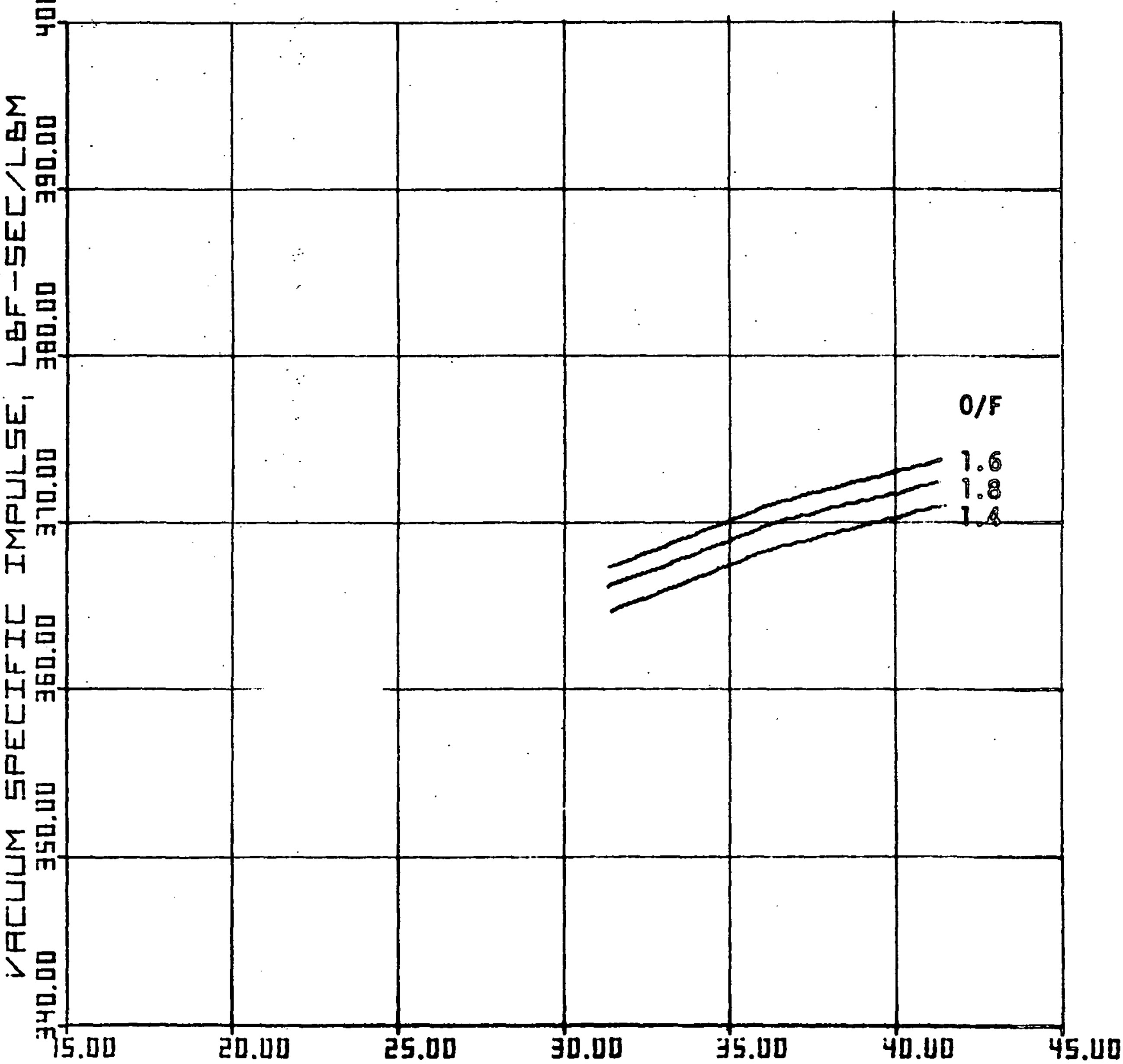
FLUORINE/HYDRAZINE ENGINE STUDY



FLUORINE/HYDRAZINE ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

CHAMBER PRESSURE = 80.
CHAMBER LENGTH = 12.0
CONTRACTION RATIO = 1.50
PERCENT FUEL FILM COOLING = 13.4



FLUORINE/HYDRAZINE ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

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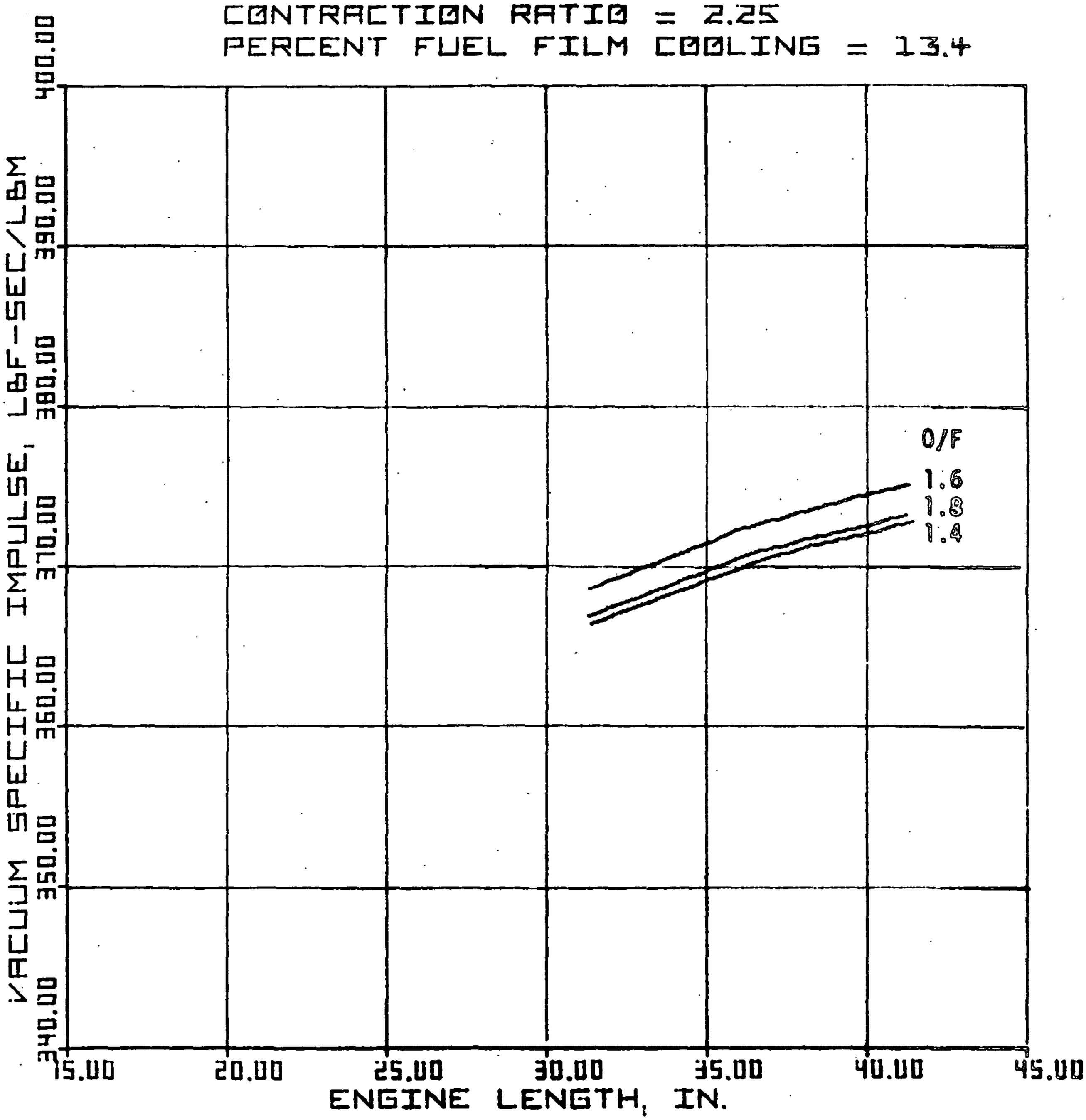
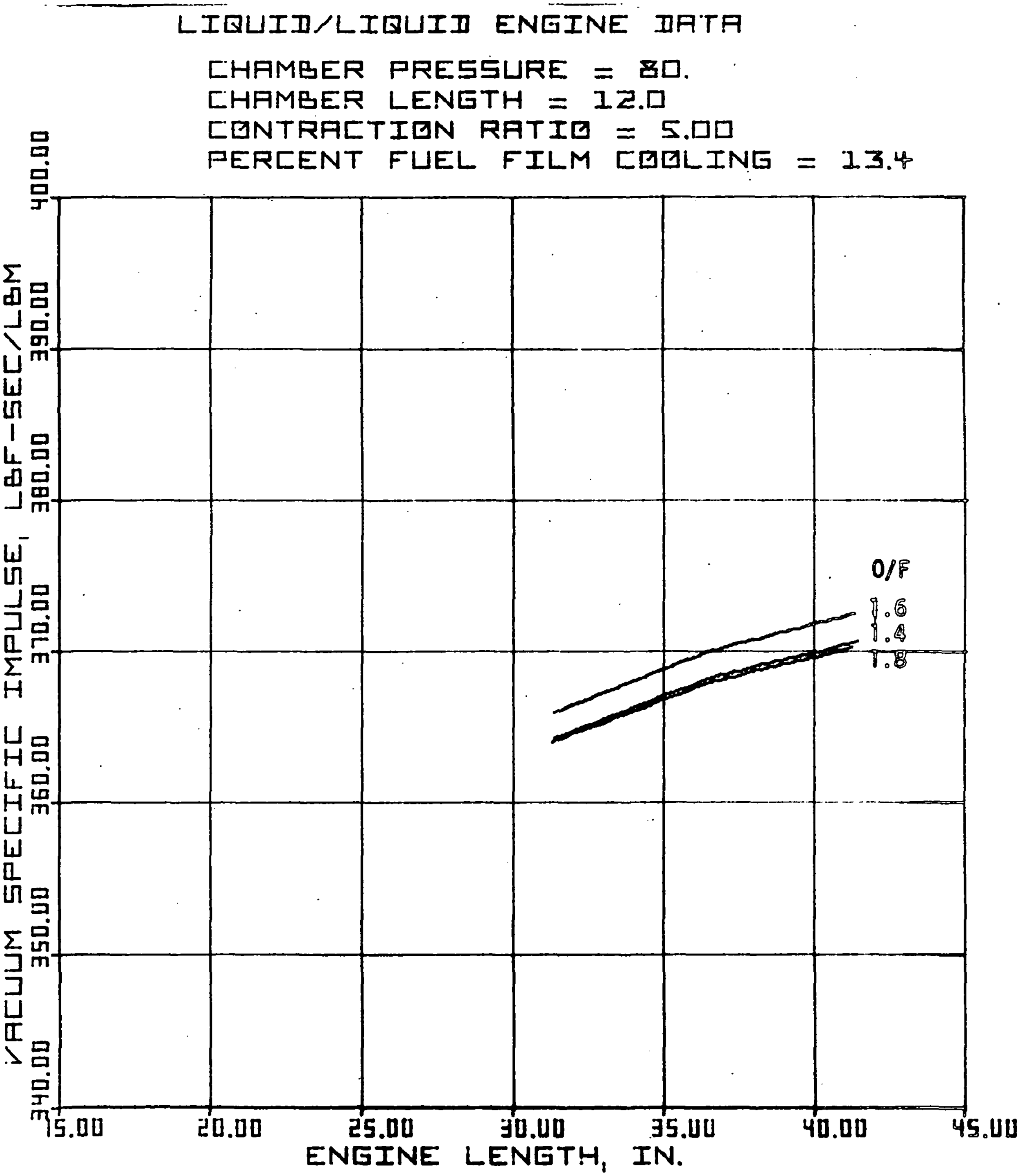
CHAMBER LENGTH = 12.0
CONTRACTION RATIO = 2.25
PERCENT FUEL FILM COOLING = 13.4



FLUORINE/HYDRAZINE ENGINE STUDY



FLUORINE/HYDRAZINE
ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

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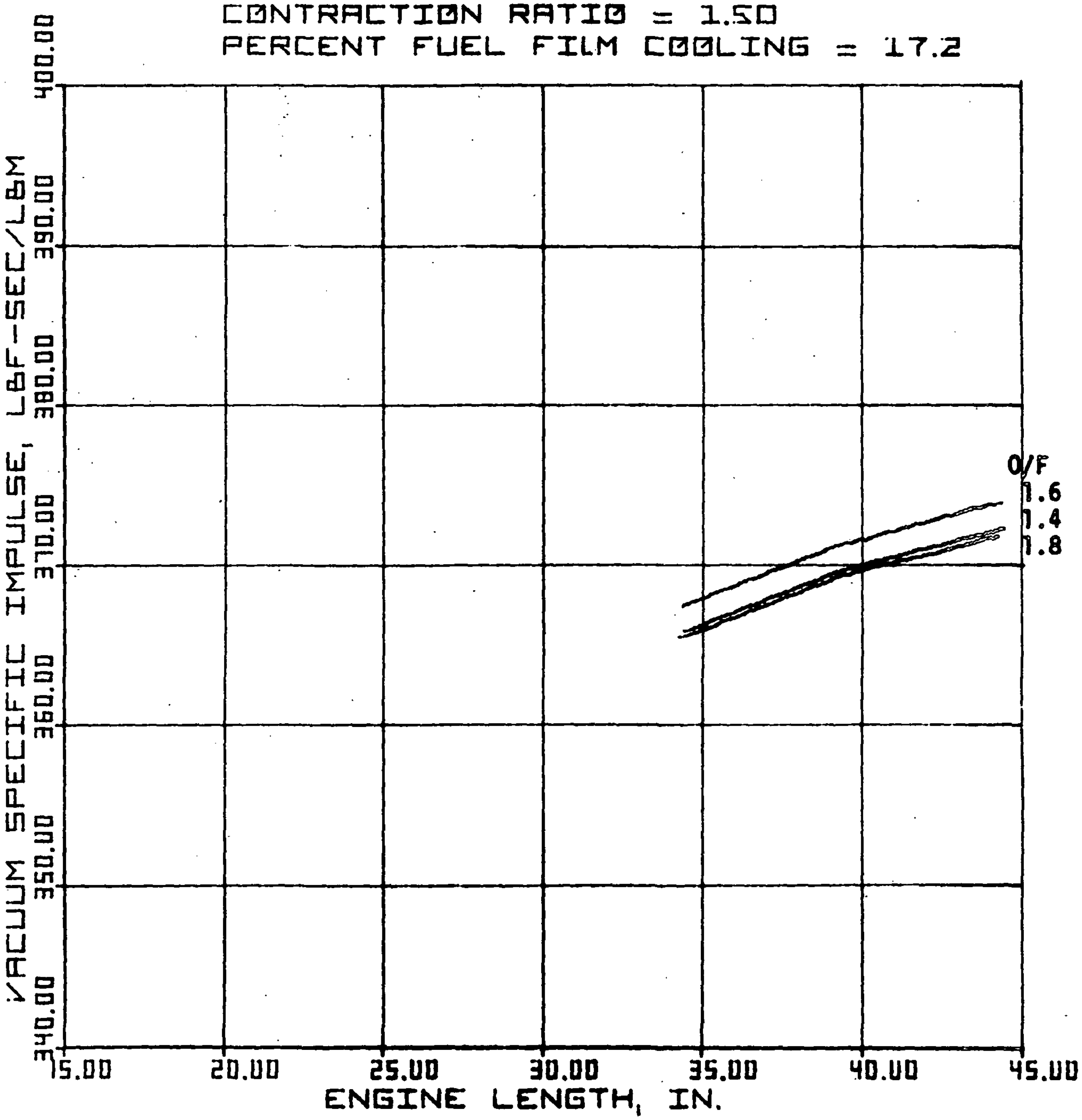
CONTRACTION RATIO = 1.50
PERCENT FUEL FILM COOLING = 17.2



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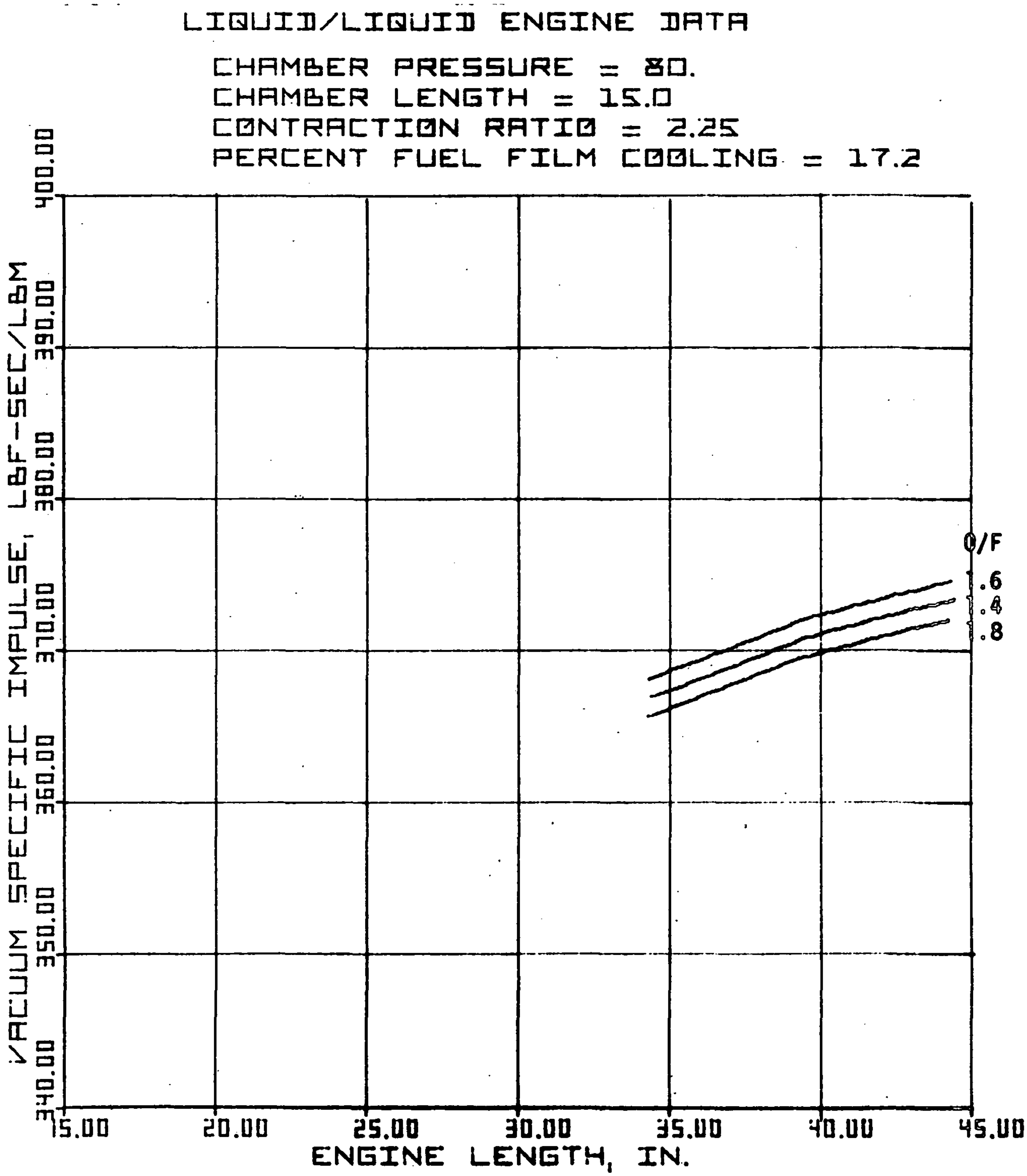
FLUORINE/HYDRAZINE ENGINE STUDY



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FLUORINE/HYDRAZINE ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

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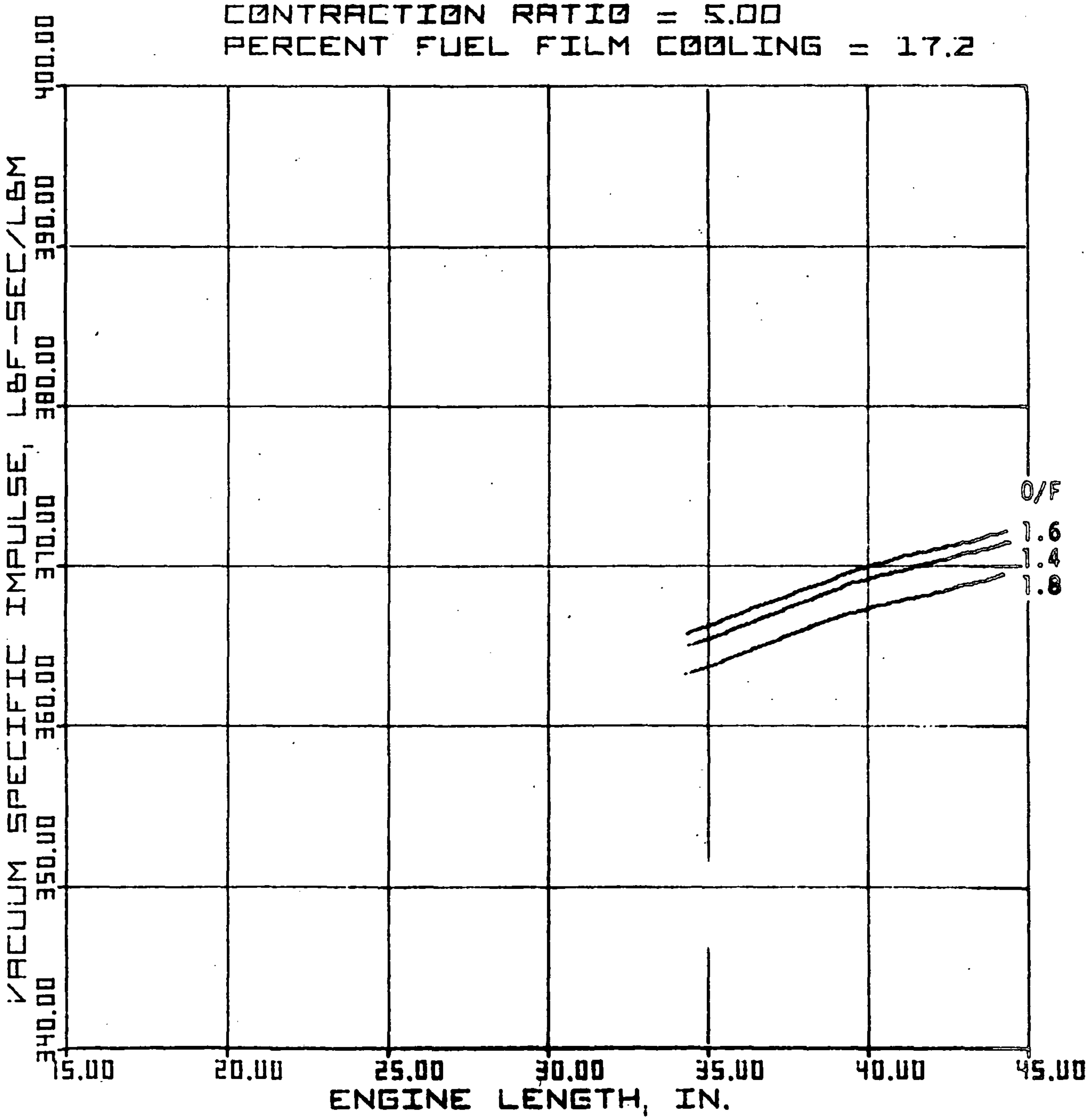
PERCENT FUEL FILM COOLING = 17.2



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FLUORINE/HYDRAZINE
ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

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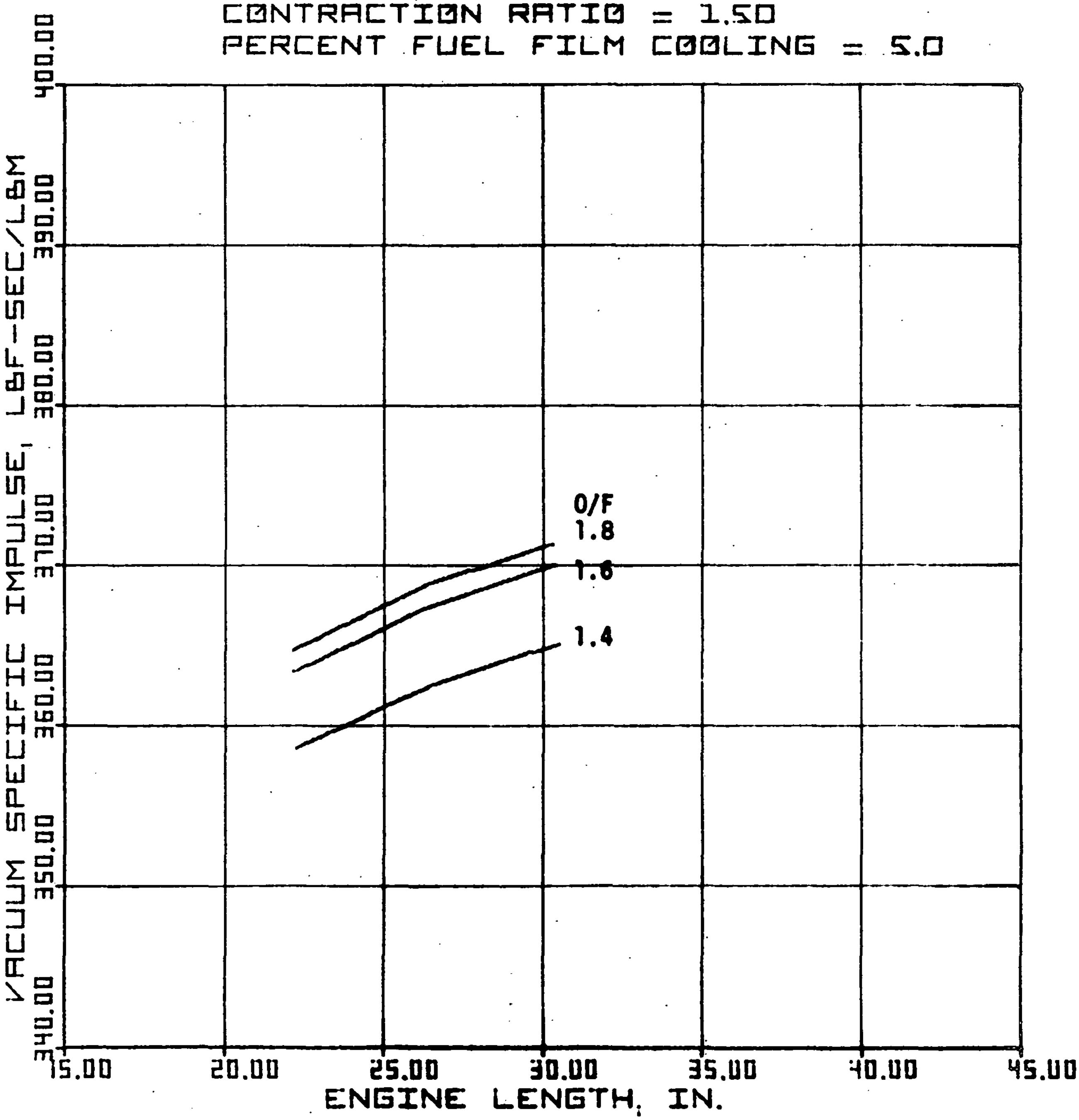
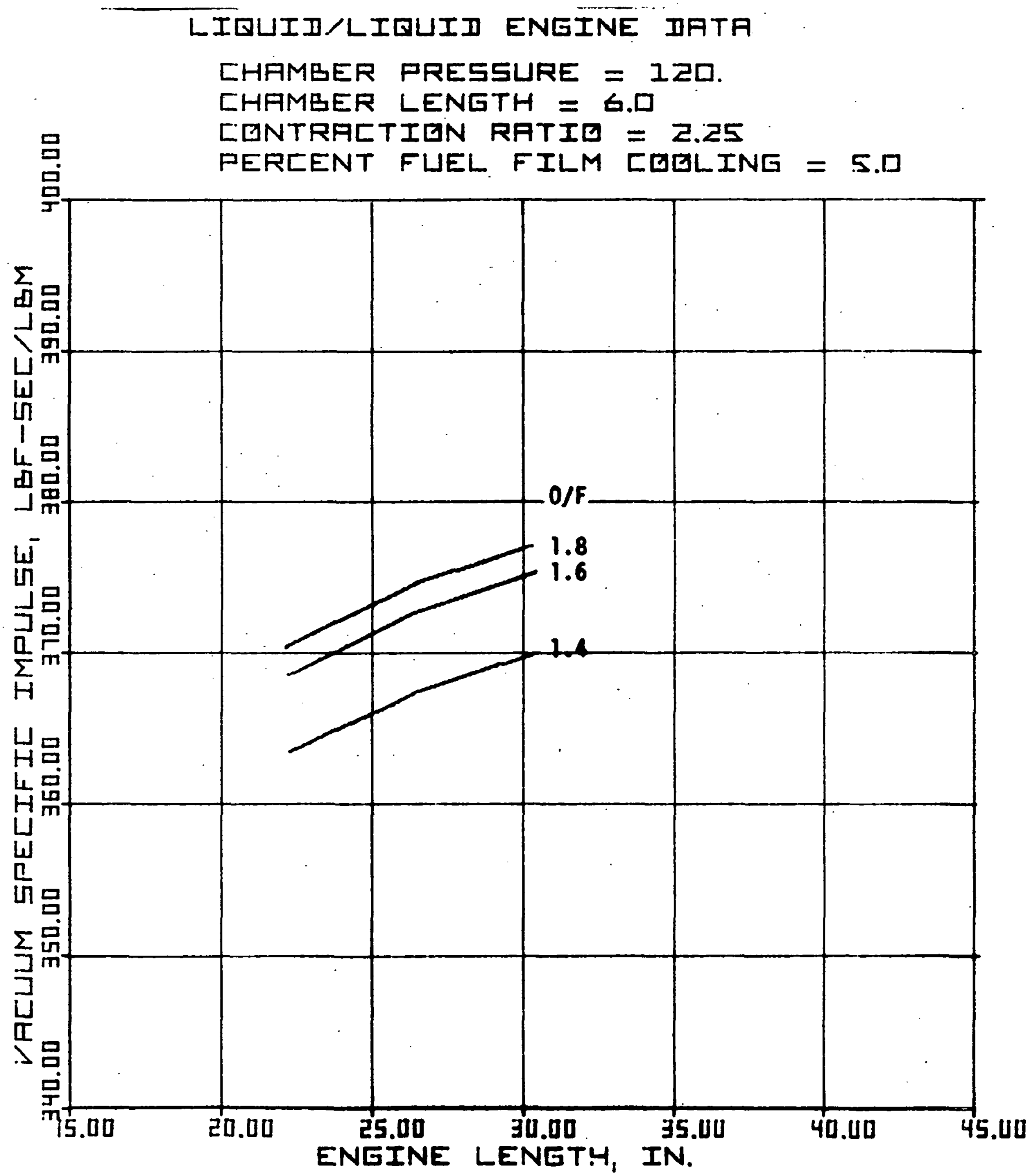
PERCENT FUEL FILM COOLING = 5.0



FLUORINE/HYDRAZINE ENGINE STUDY



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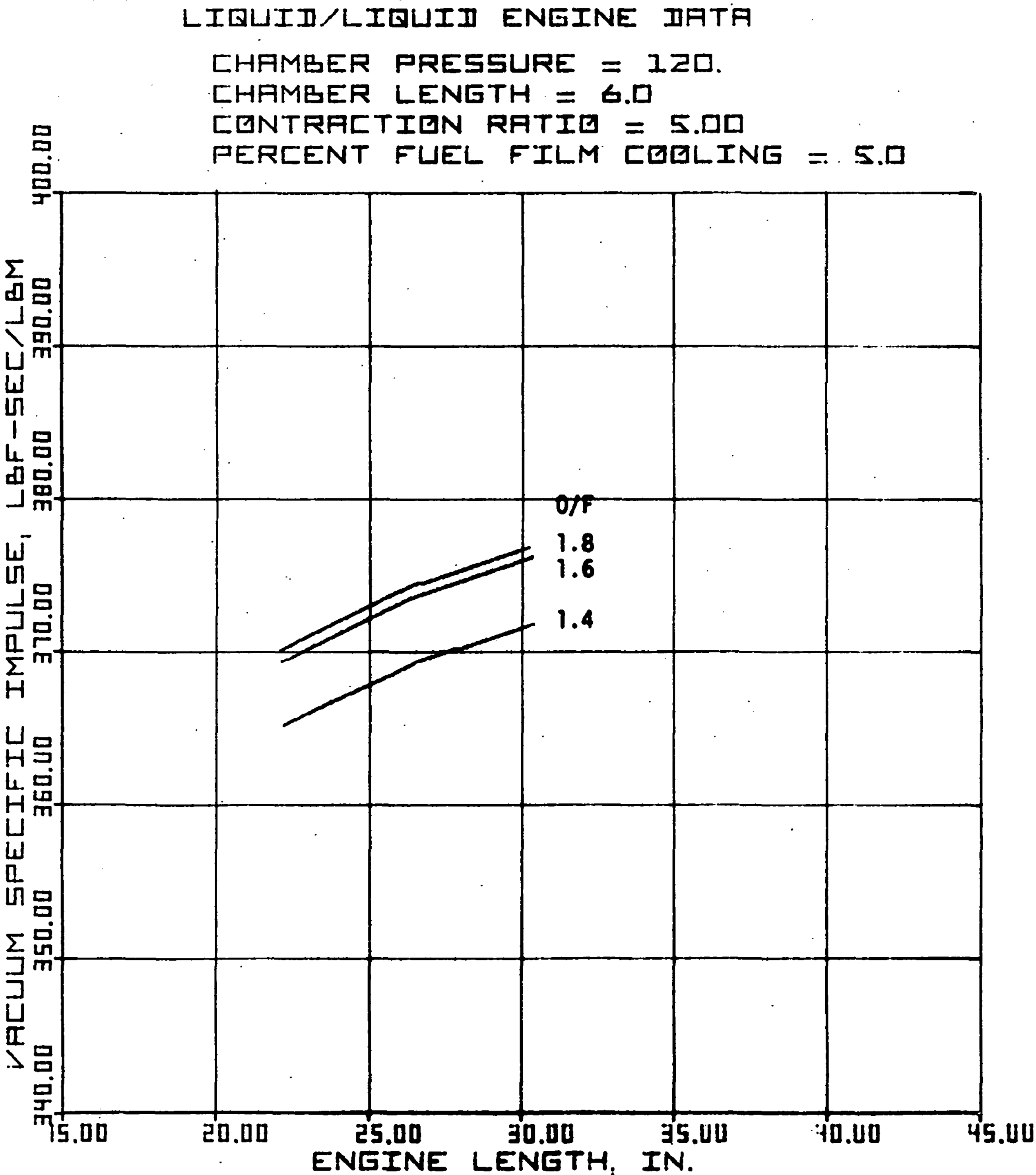

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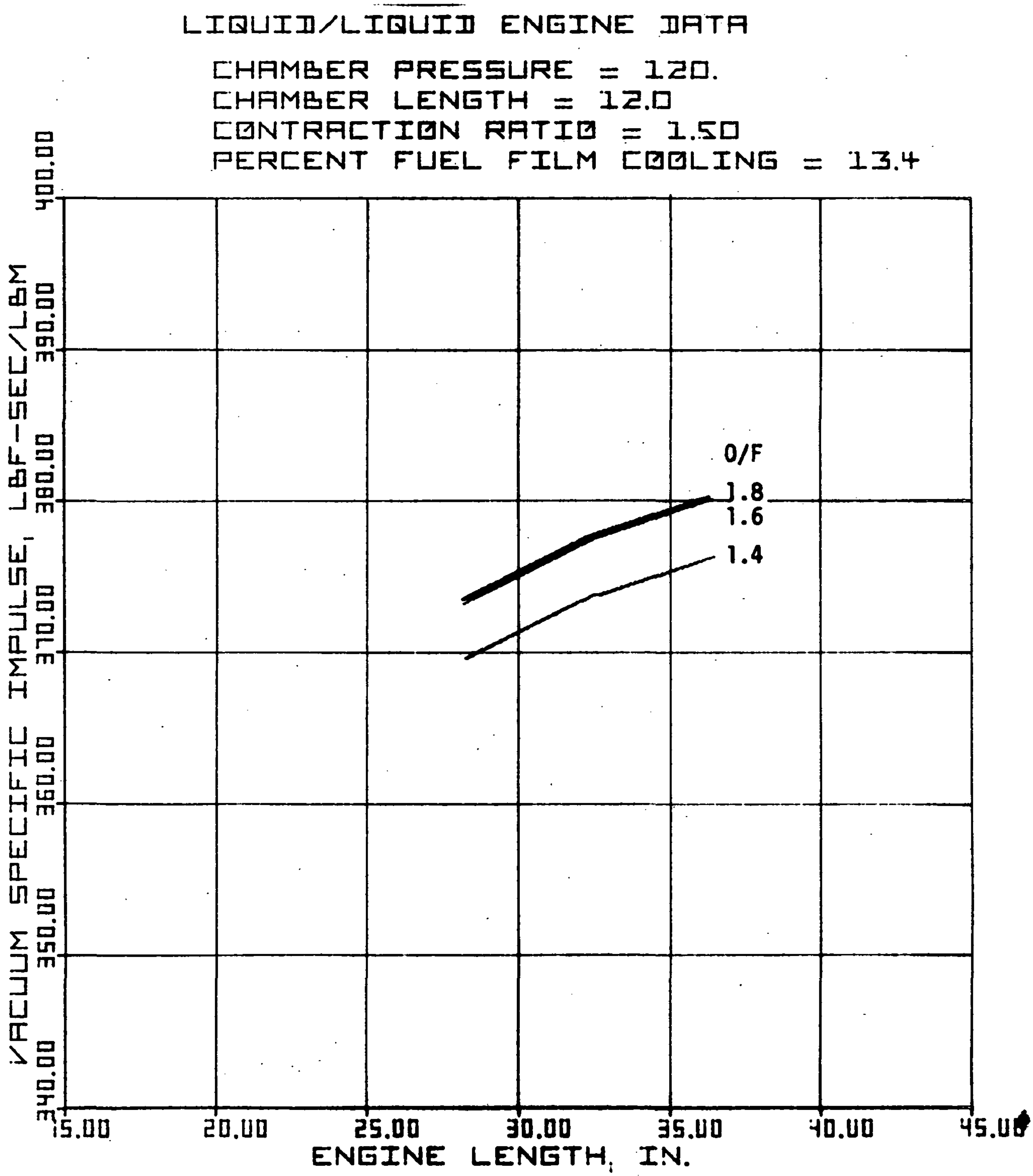
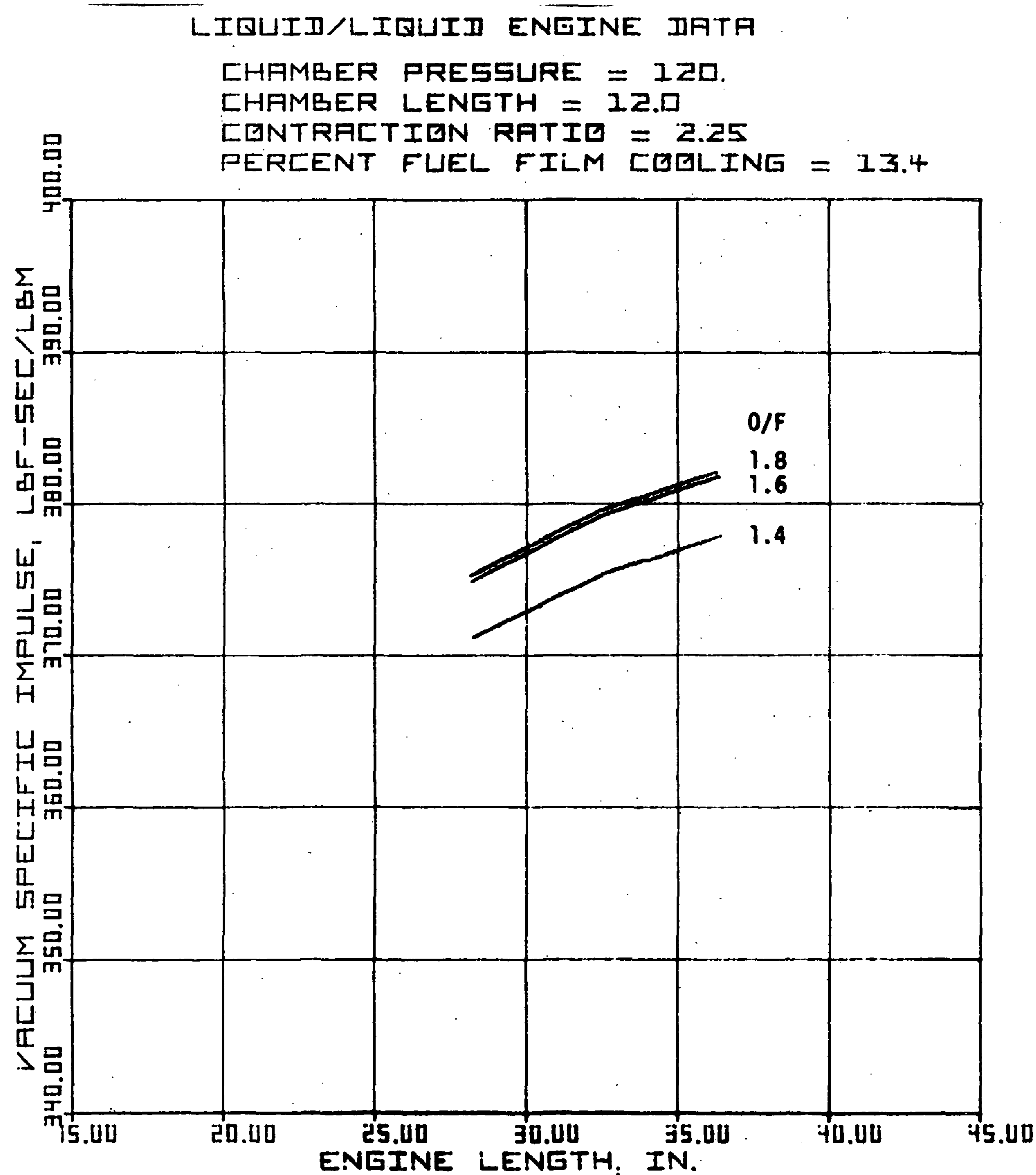


FLUORINE/HYDRAZINE ENGINE STUDY



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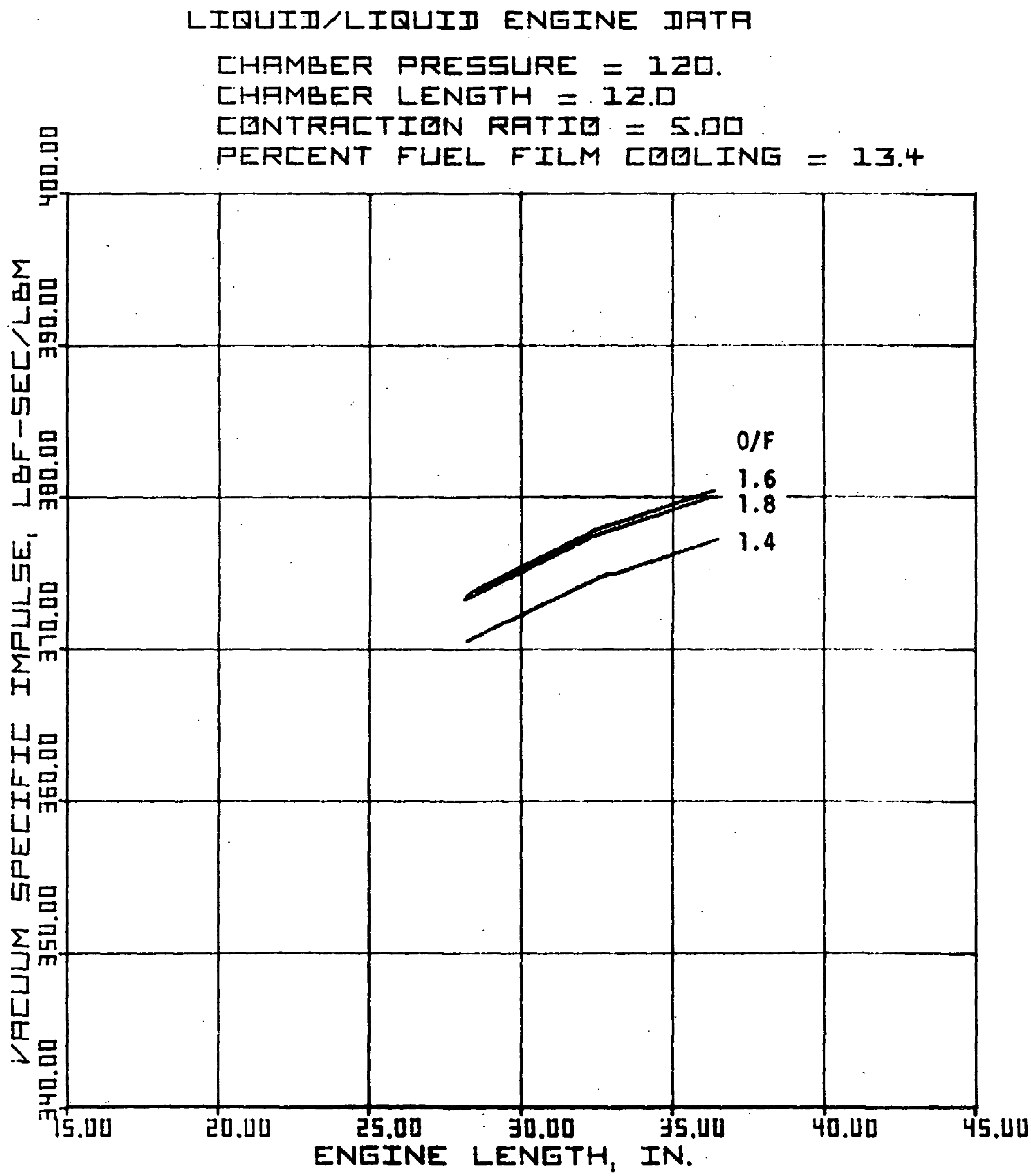
FLUORINE/HYDRAZINE ENGINE STUDY



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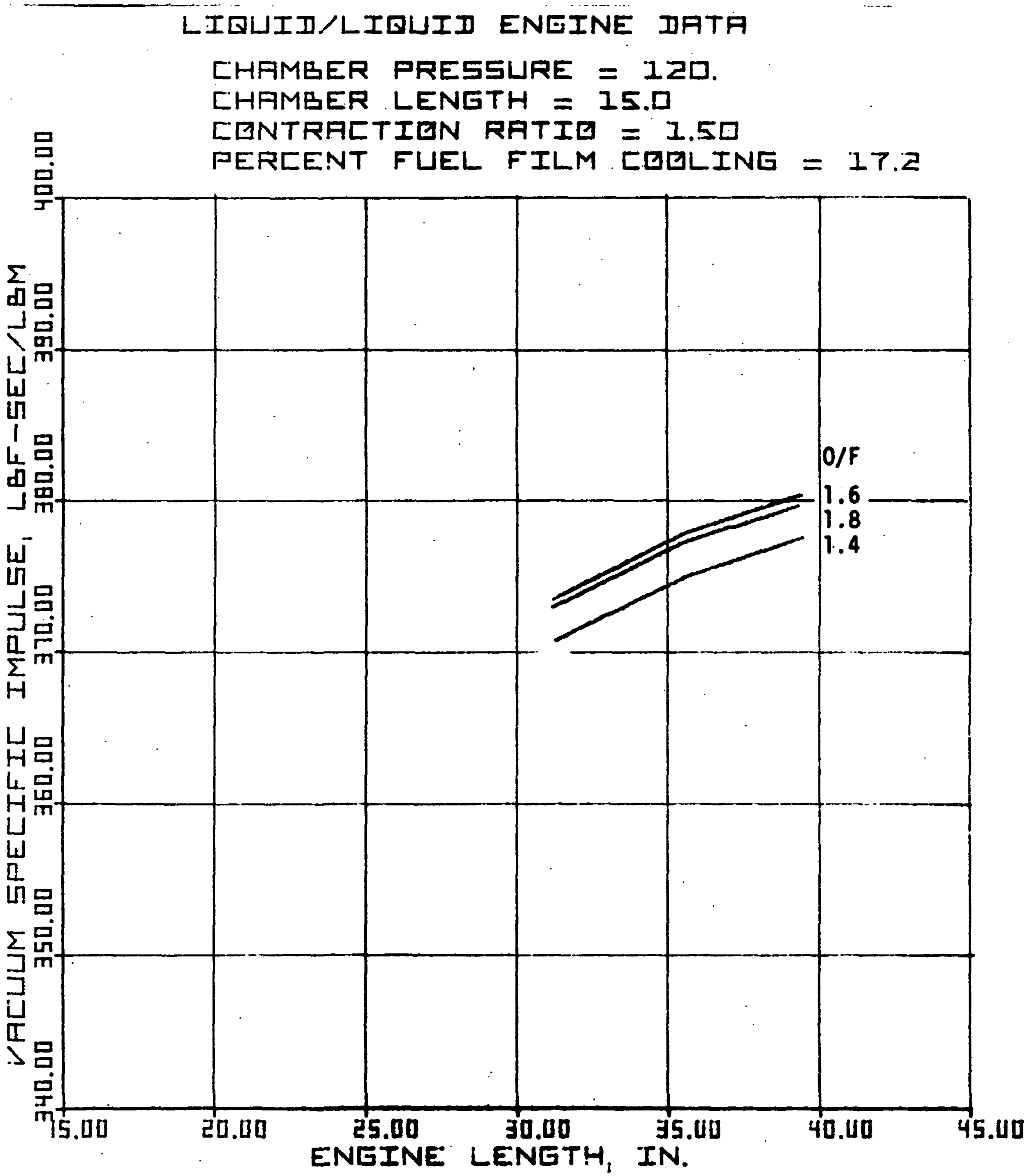
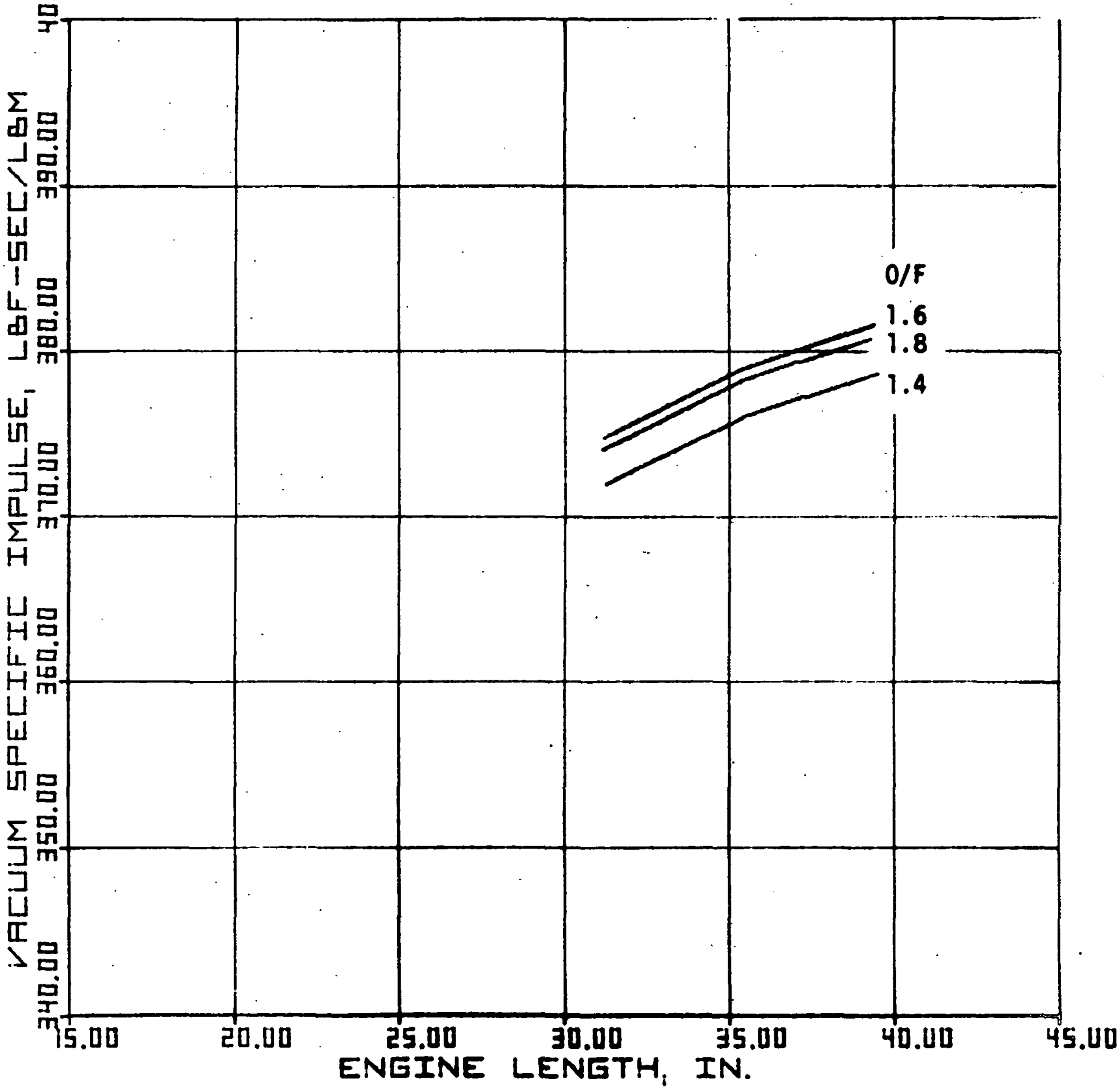


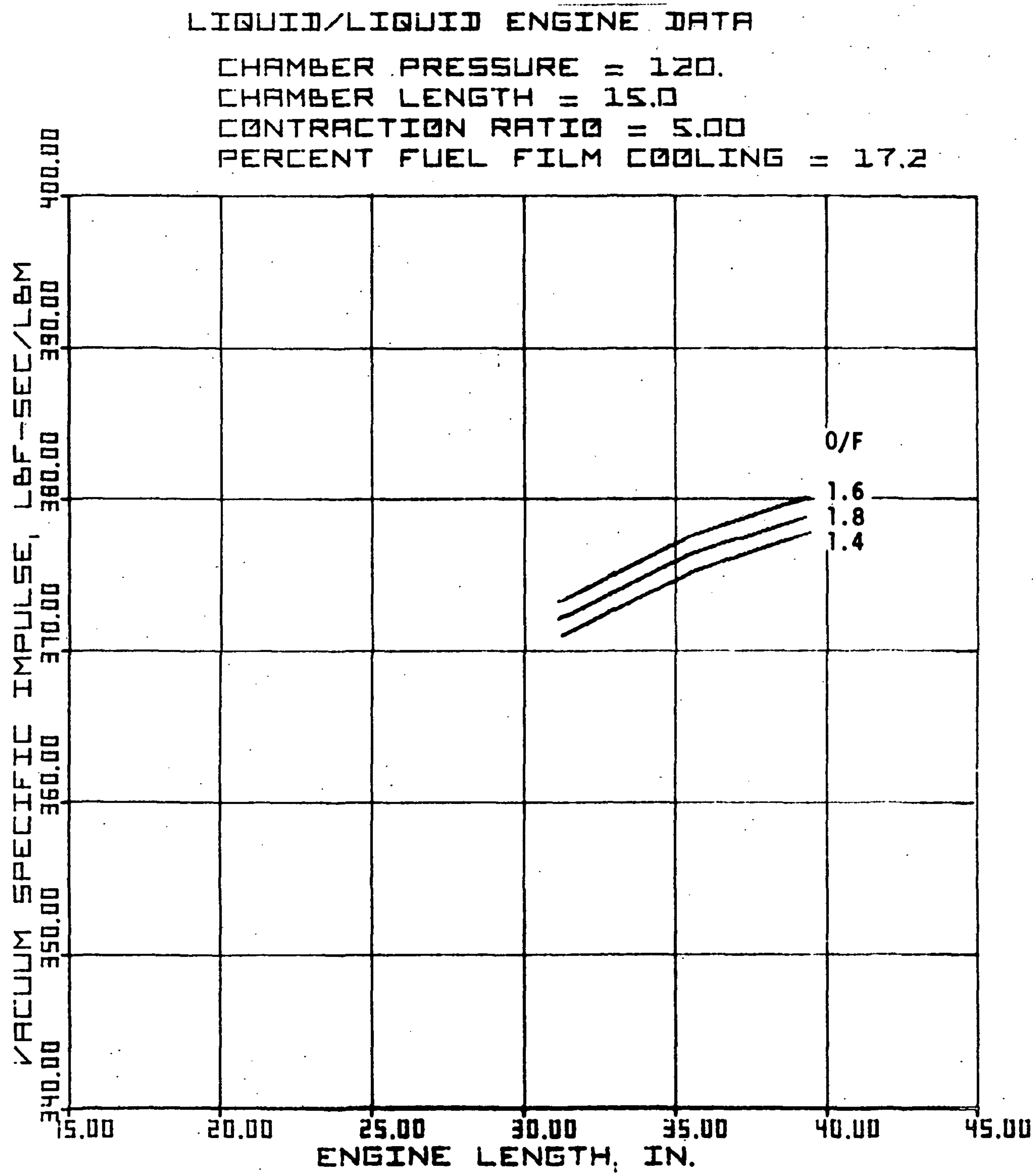
FLUORINE/HYDRAZINE ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

CHAMBER PRESSURE = 120.
CHAMBER LENGTH = 15.0
CONTRACTION RATIO = 2.25
PERCENT FUEL FILM COOLING = 17.2



FLUORINE/HYDRAZINE
ENGINE STUDY



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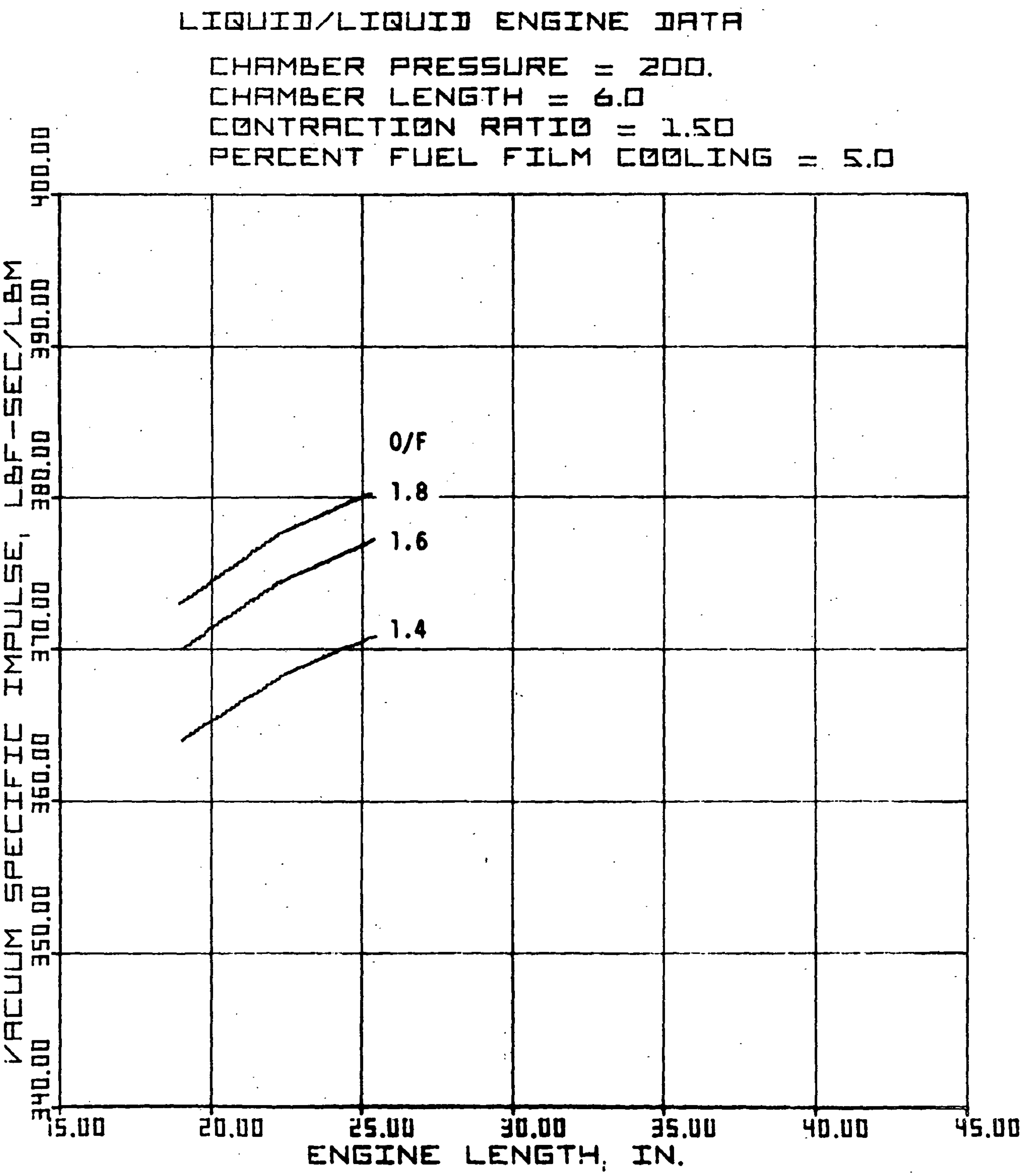
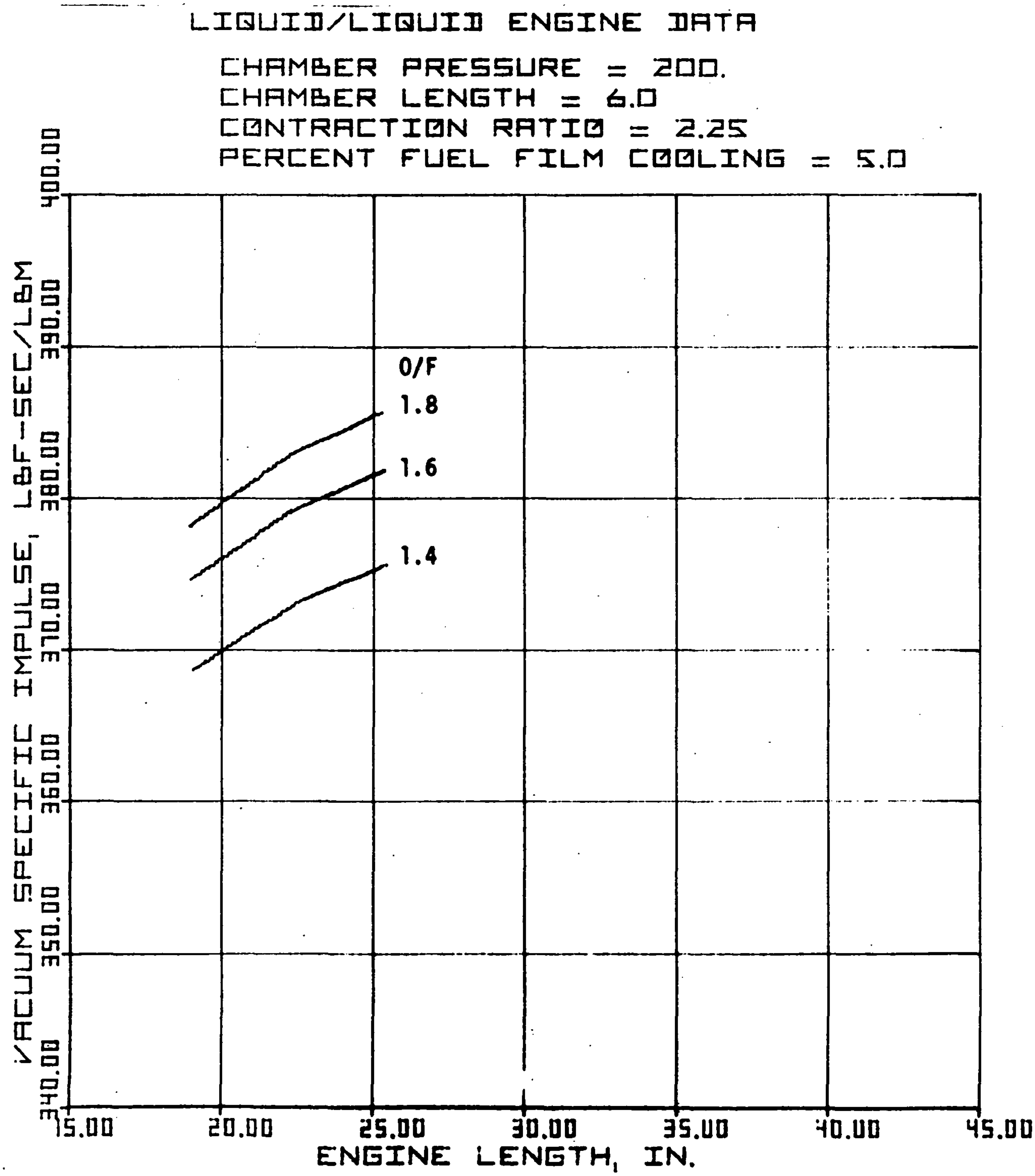
FLUORINE/HYDRAZINE ENGINE STUDY



FLUORINE/HYDRAZINE ENGINE STUDY



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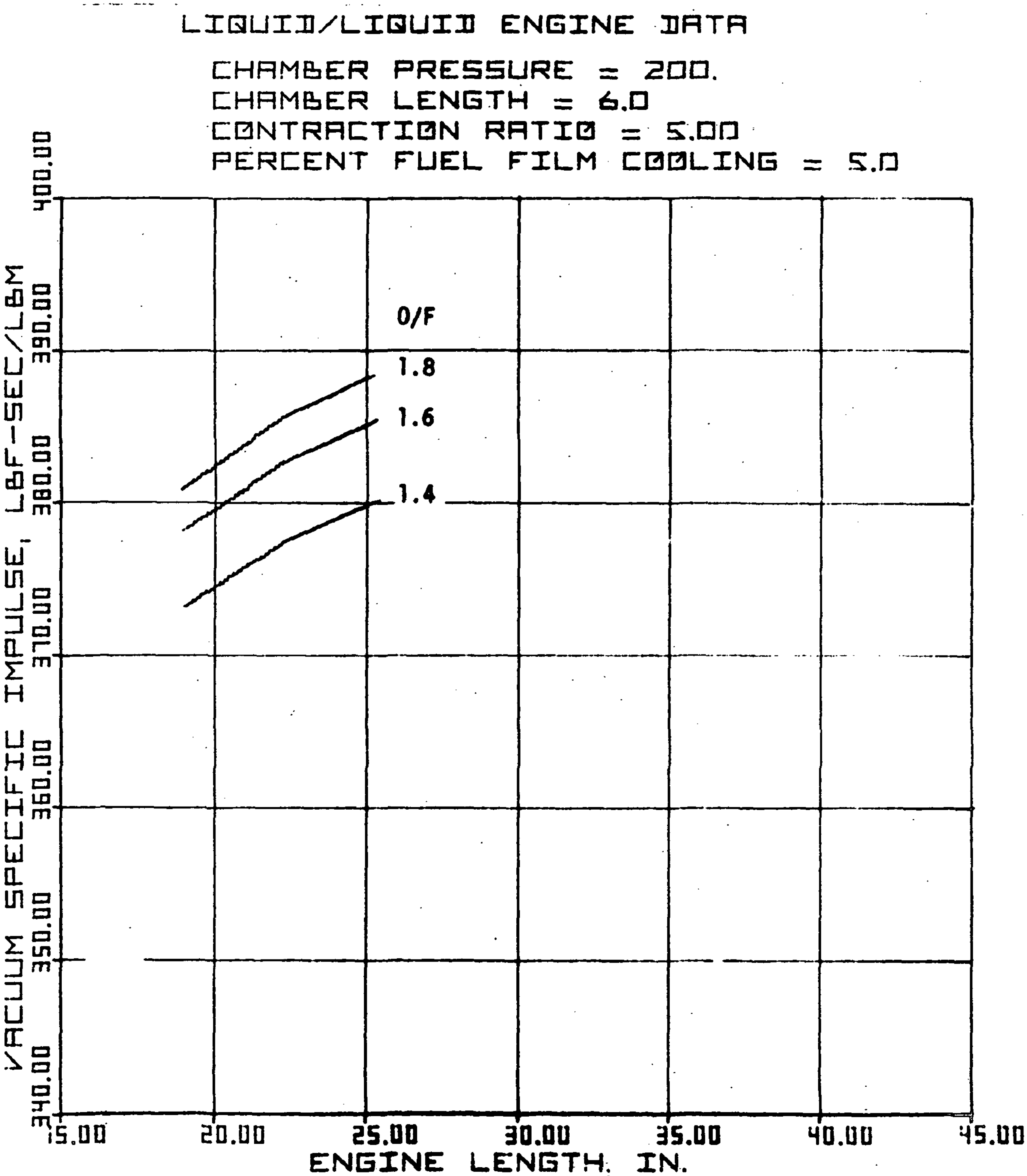
FLUORINE/HYDRAZINE ENGINE STUDY



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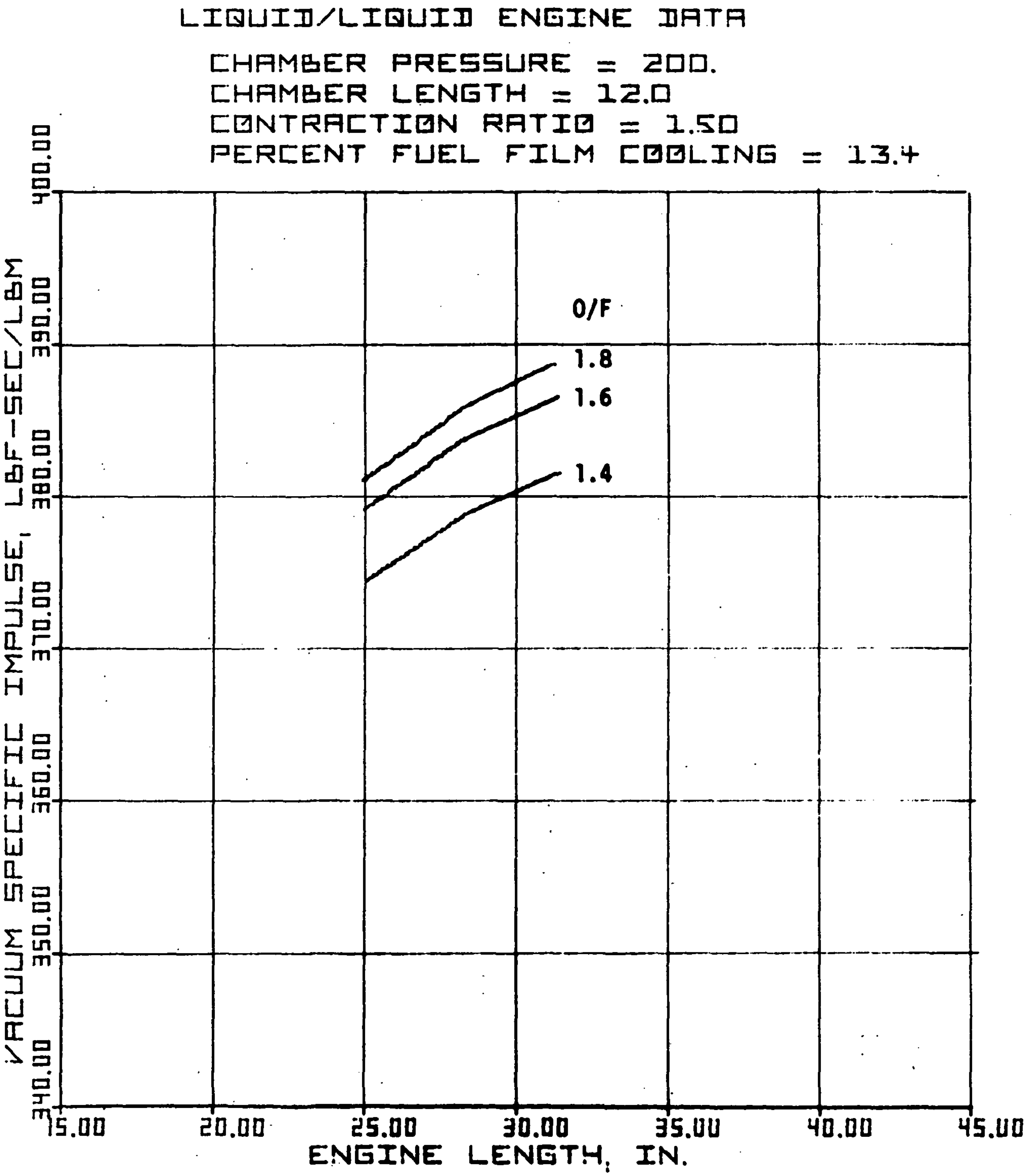

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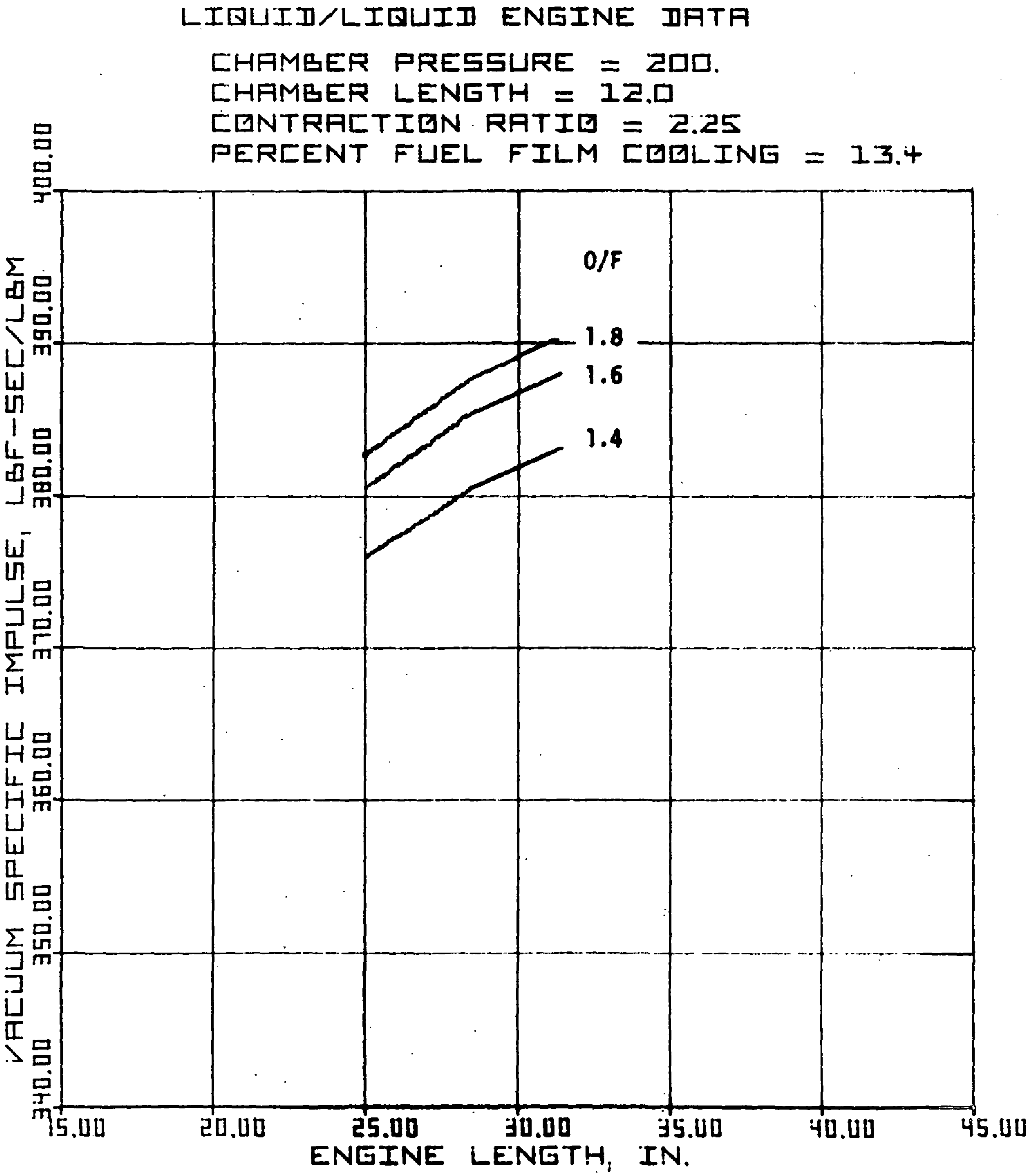
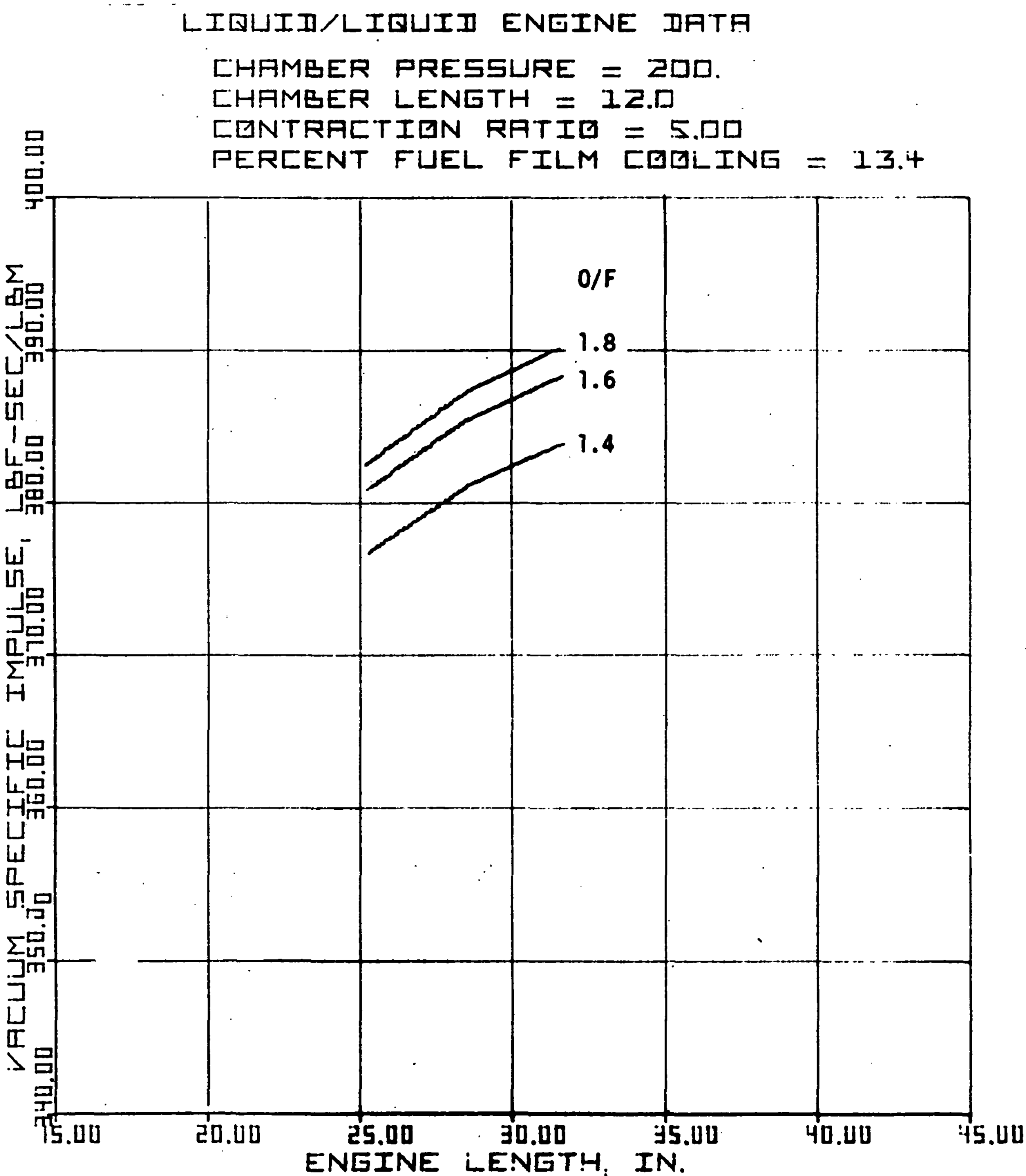


FLUORINE/HYDRAZINE ENGINE STUDY



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FLUORINE/HYDRAZINE ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

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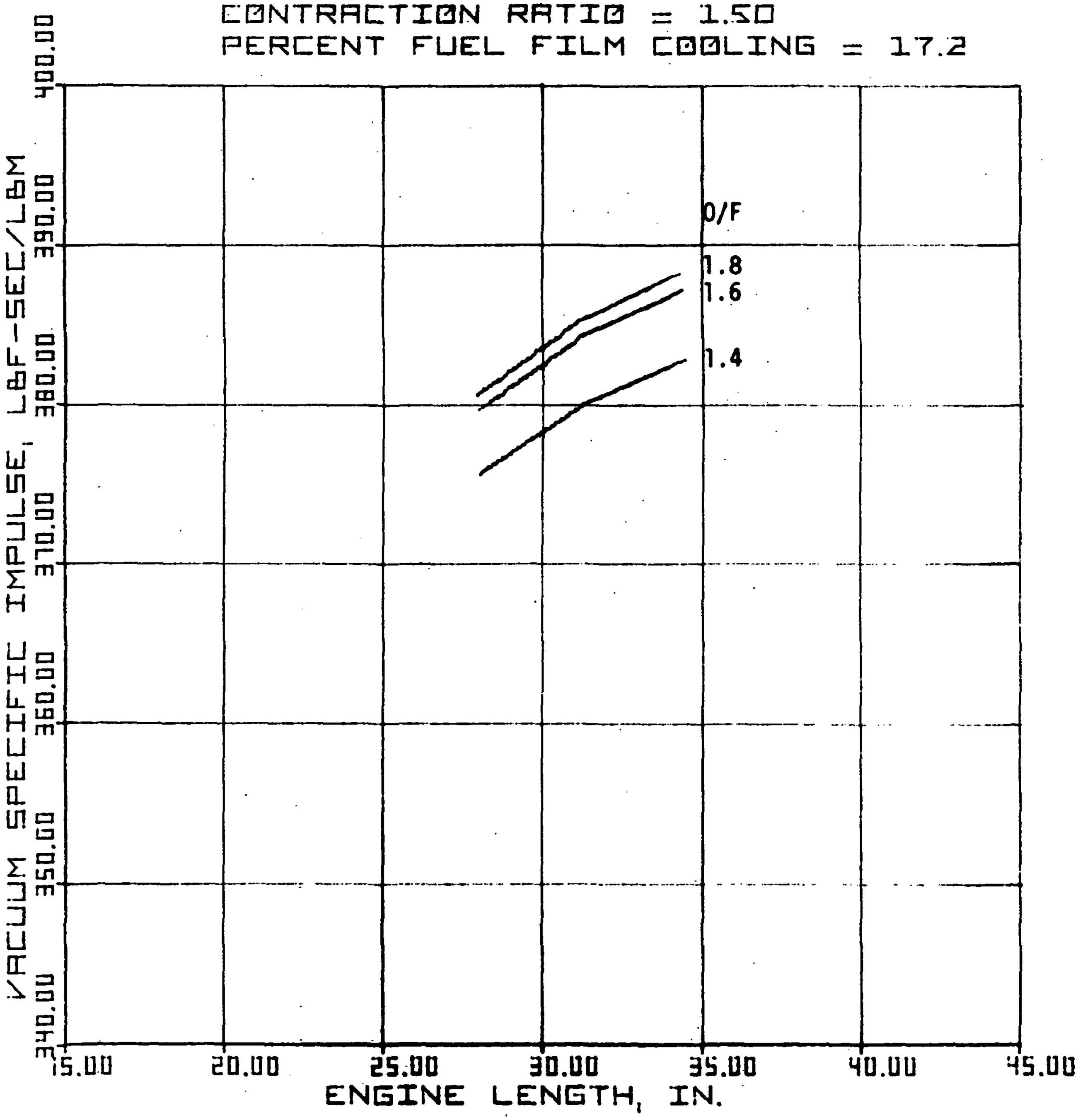
PERCENT FUEL FILM COOLING = 17.2



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FLUORINE/HYDRAZINE ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

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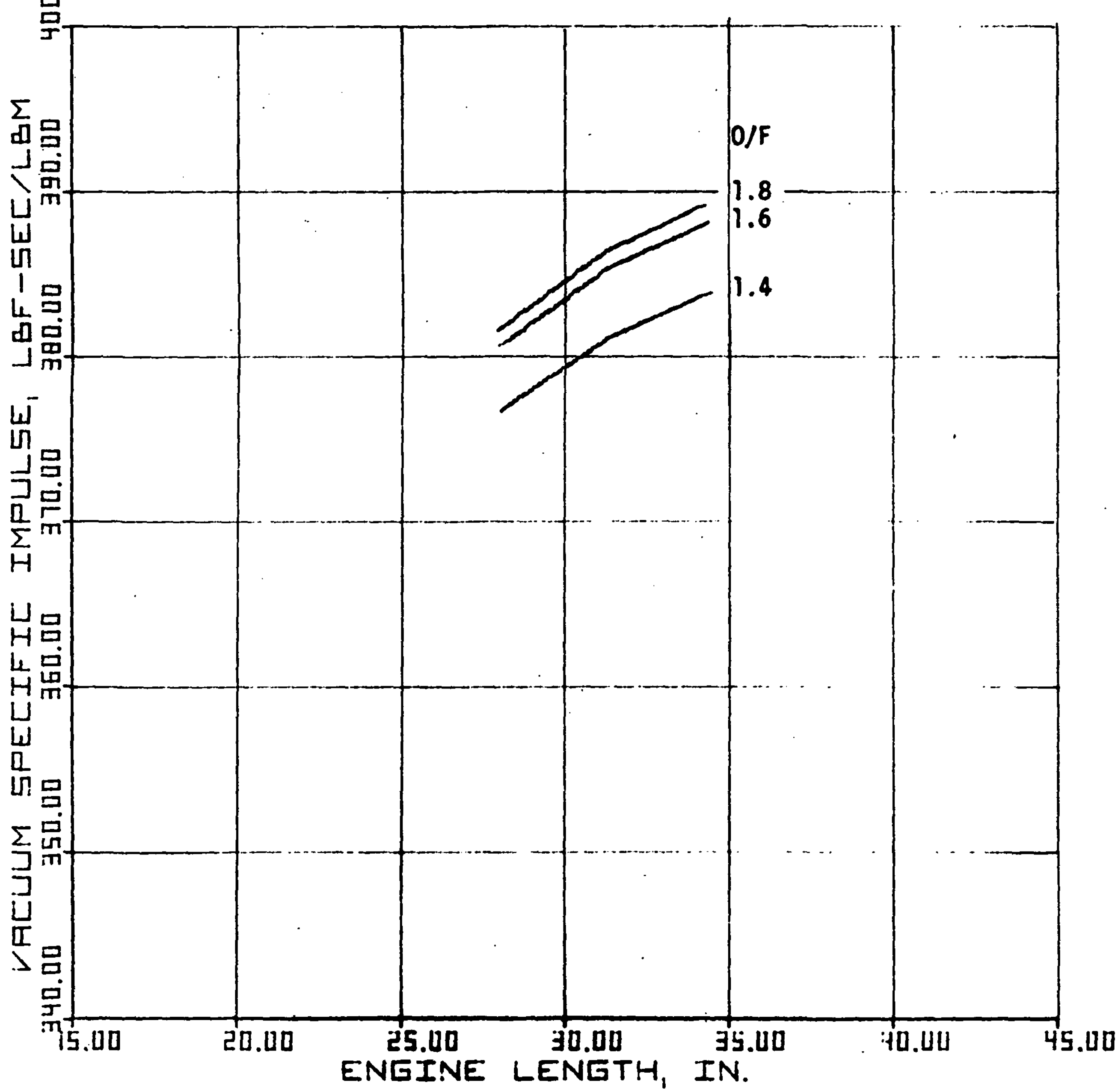
PERCENT FUEL FILM COOLING = 17.2



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FLUORINE/HYDRAZINE ENGINE STUDY

LIQUID/LIQUID ENGINE DATA

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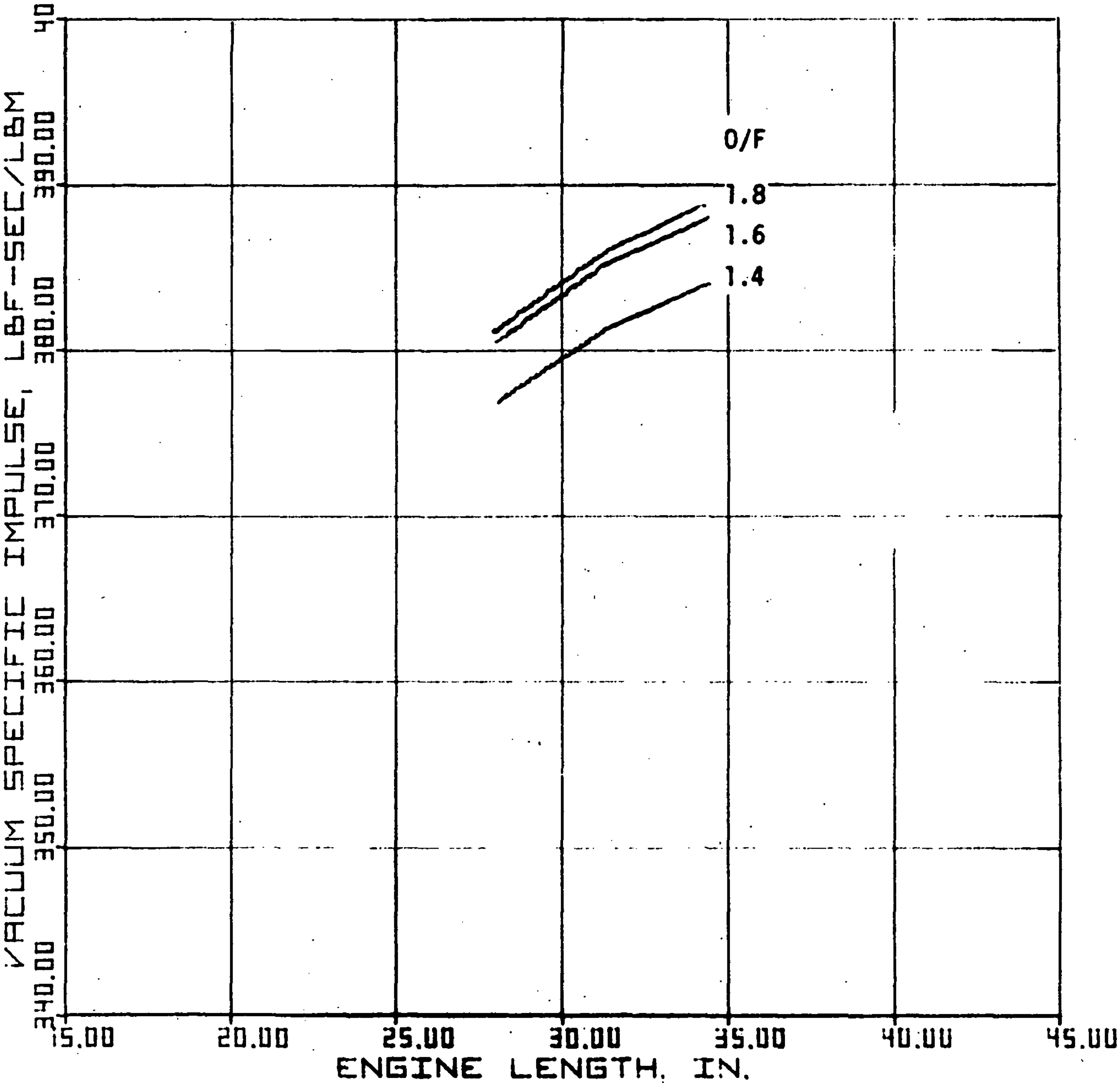
PERCENT FUEL FILM COOLING = 17.2



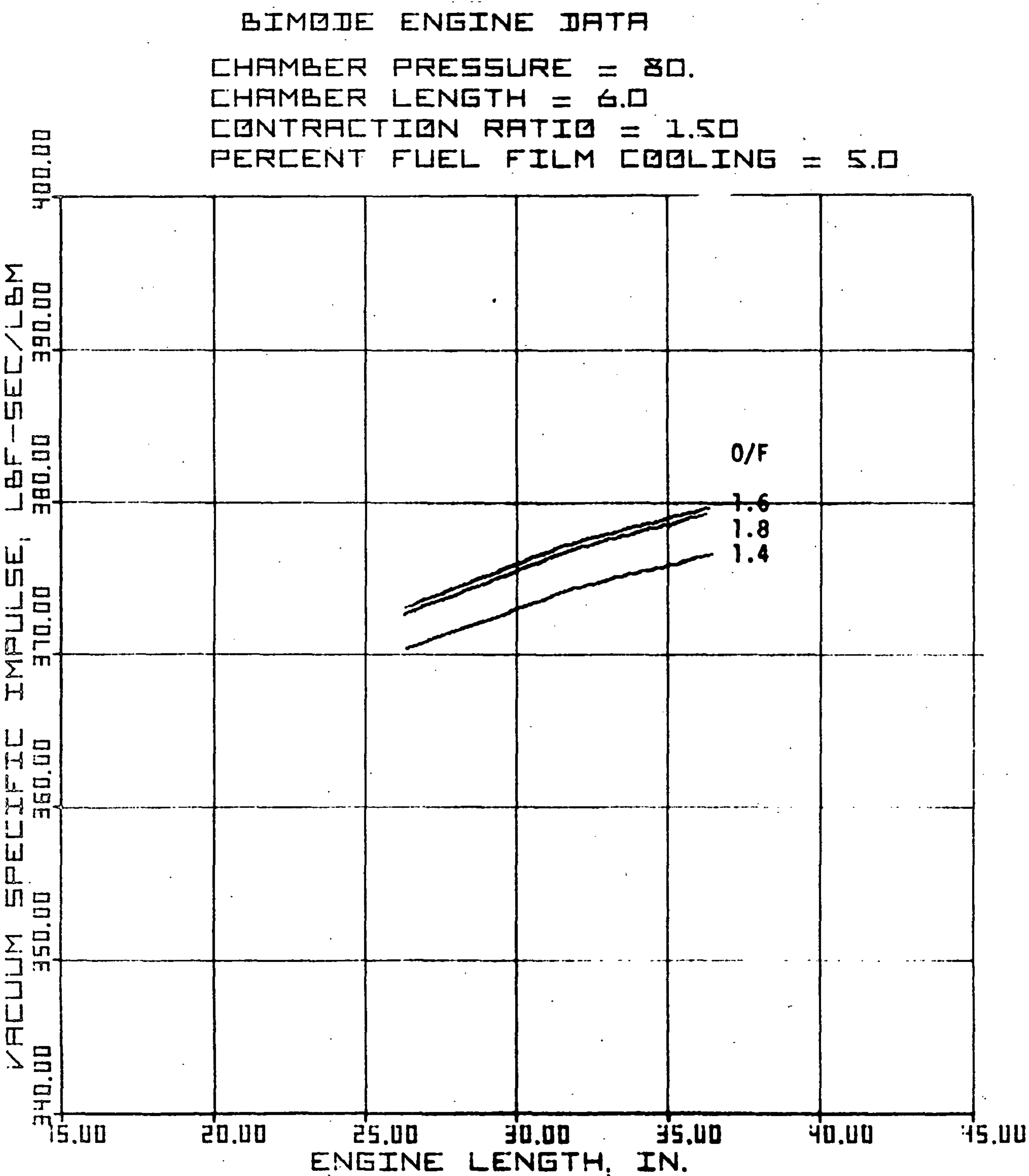
193

APPENDIX A

FIGURE SET D

BIMODAL ENGINE SPECIFIC IMPULSE VERSUS ENGINE LENGTH

FLUORINE/HYDRAZINE ENGINE STUDY



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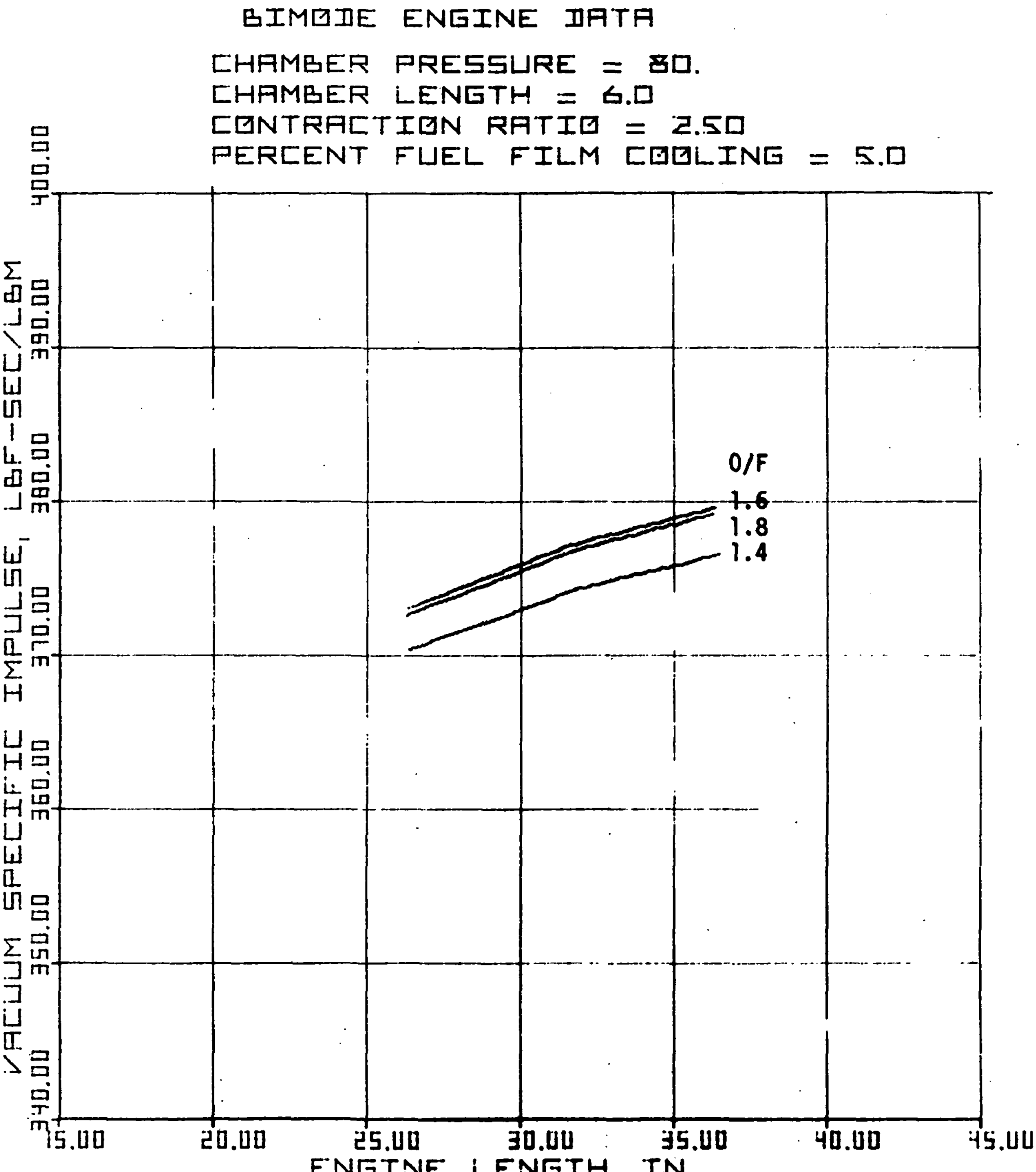
FLUORINE/HYDRAZINE ENGINE STUDY



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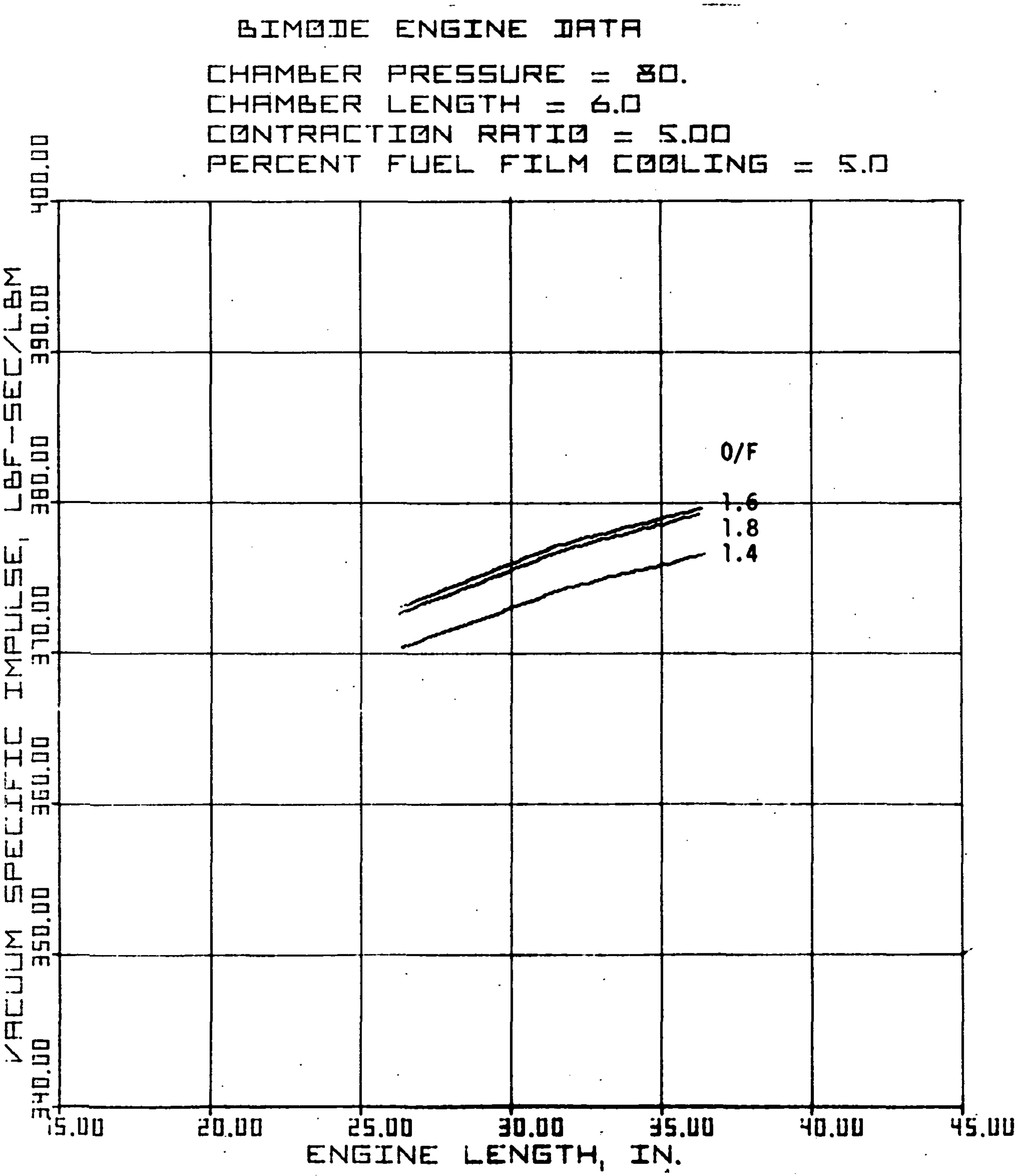
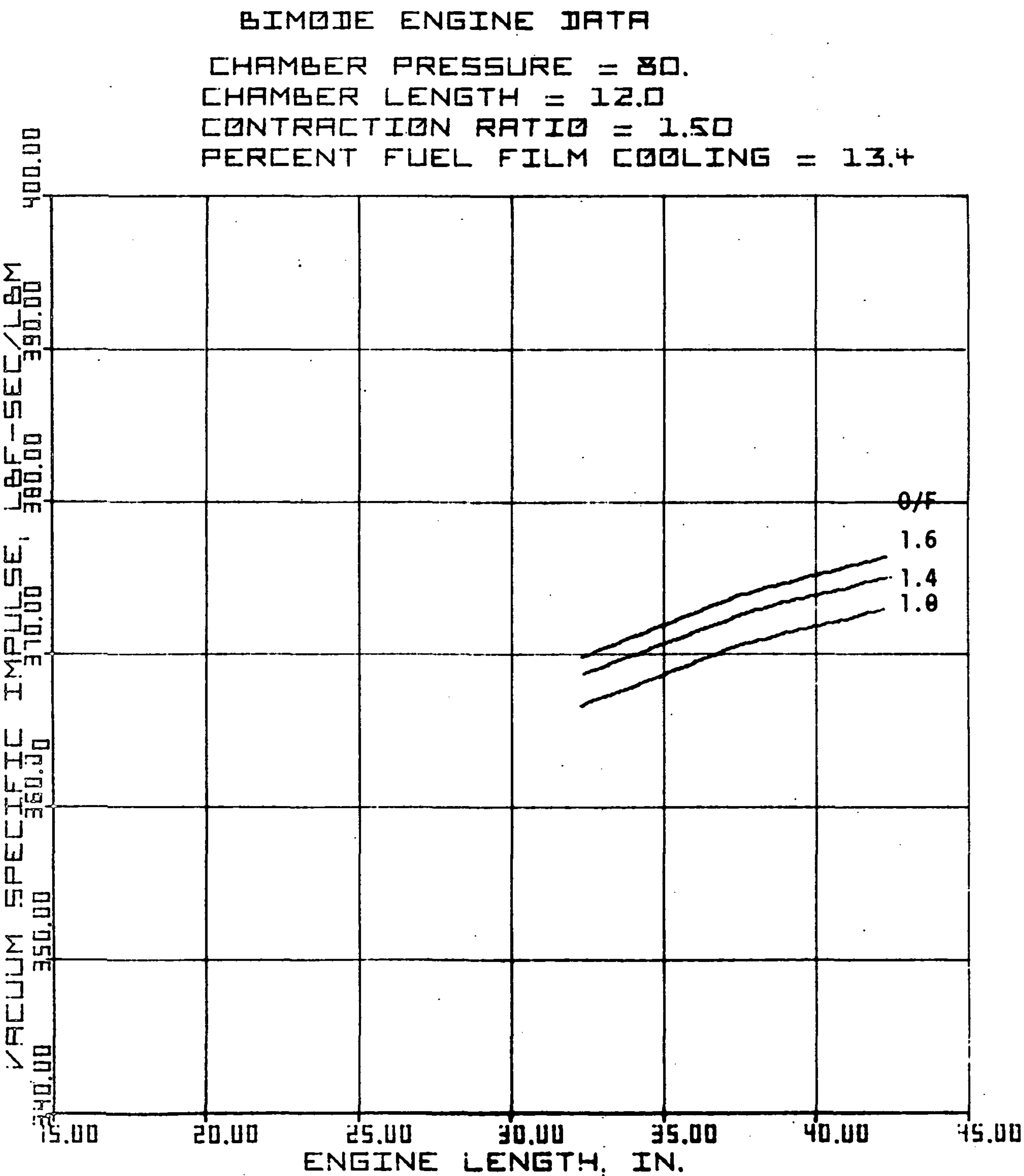
FLUORINE/HYDRAZINE ENGINE STUDY



FLUORINE/HYDRAZINE
ENGINE STUDY

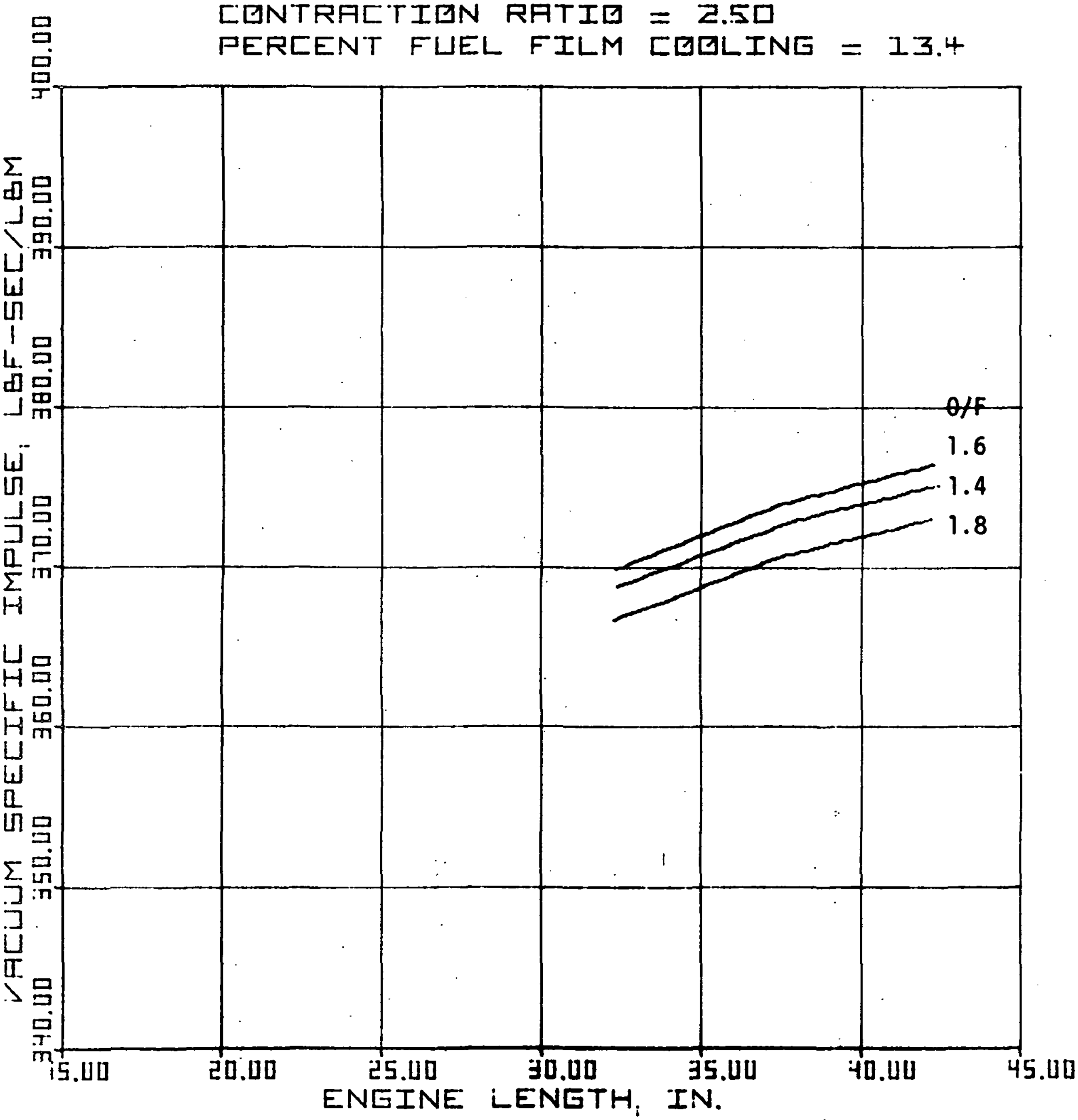


198

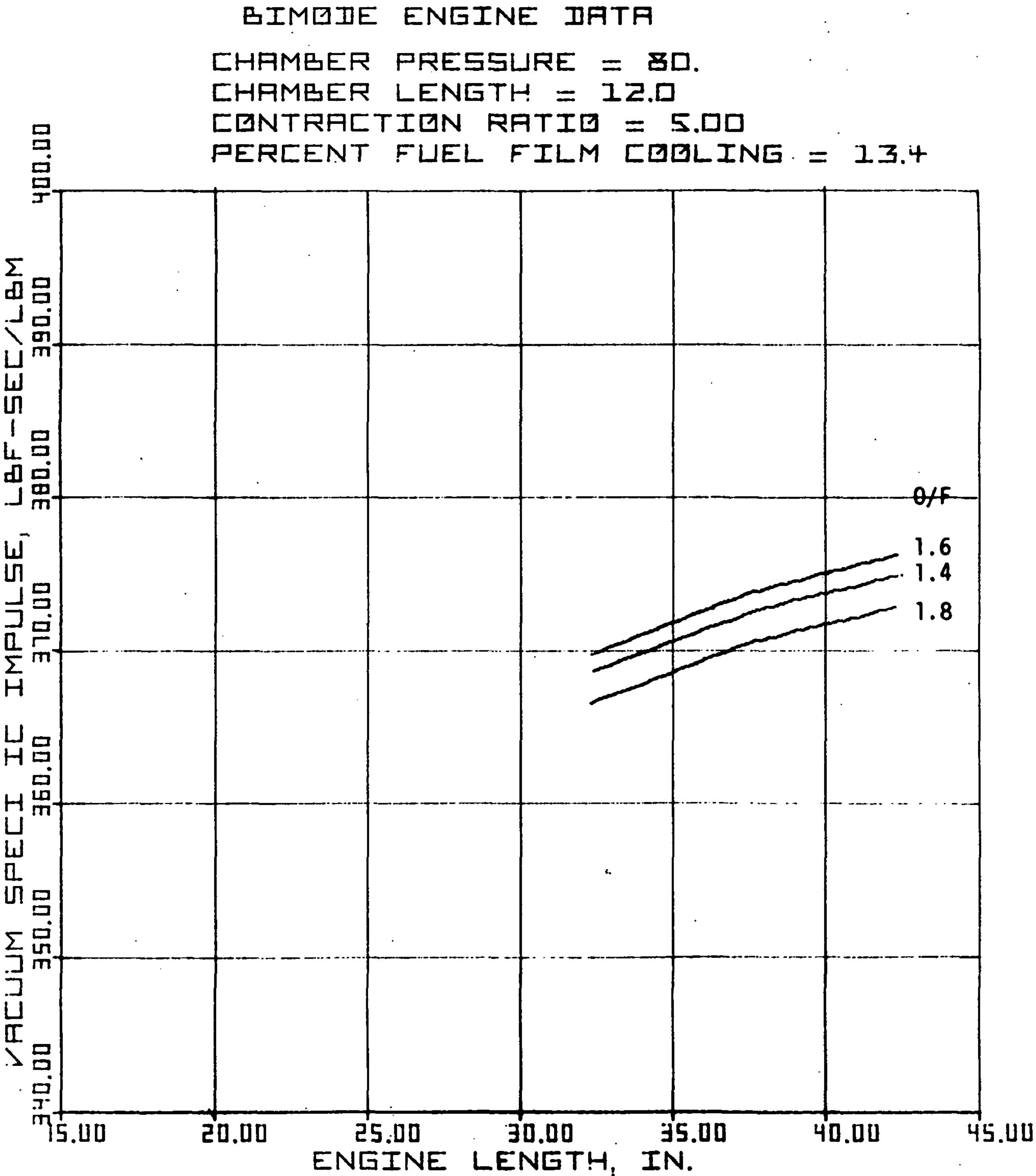
FLUORINE/HYDRAZINE
ENGINE STUDY

BIMODE ENGINE DATA

CHAMBER PRESSURE = 80.
CHAMBER LENGTH = 12.0
CONTRACTION RATIO = 2.50
PERCENT FUEL FILM COOLING = 13.4



FLUORINE/HYDRAZINE ENGINE STUDY



FLUORINE/HYDRAZINE
ENGINE STUDY

BIMODE ENGINE DATA

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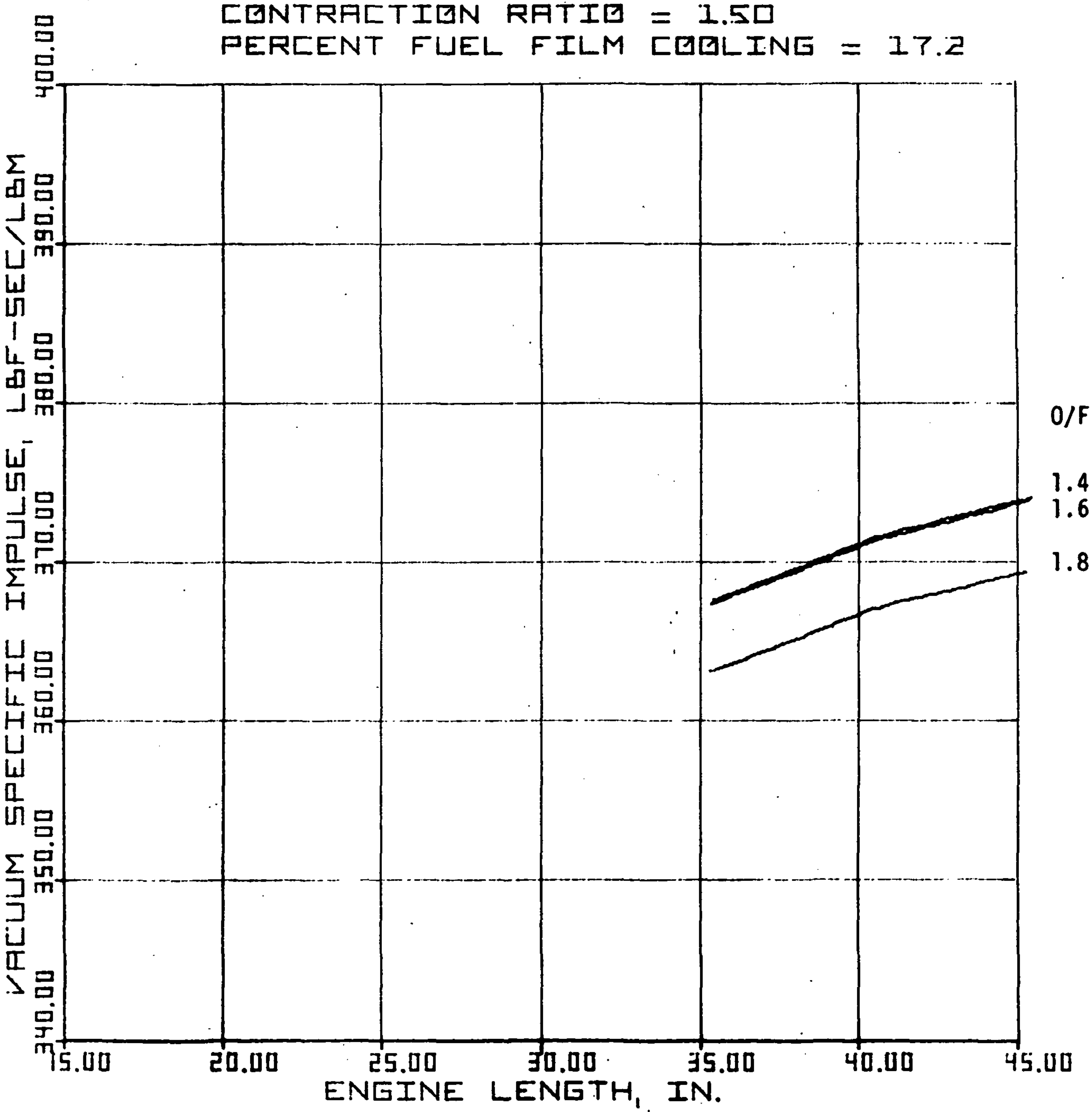
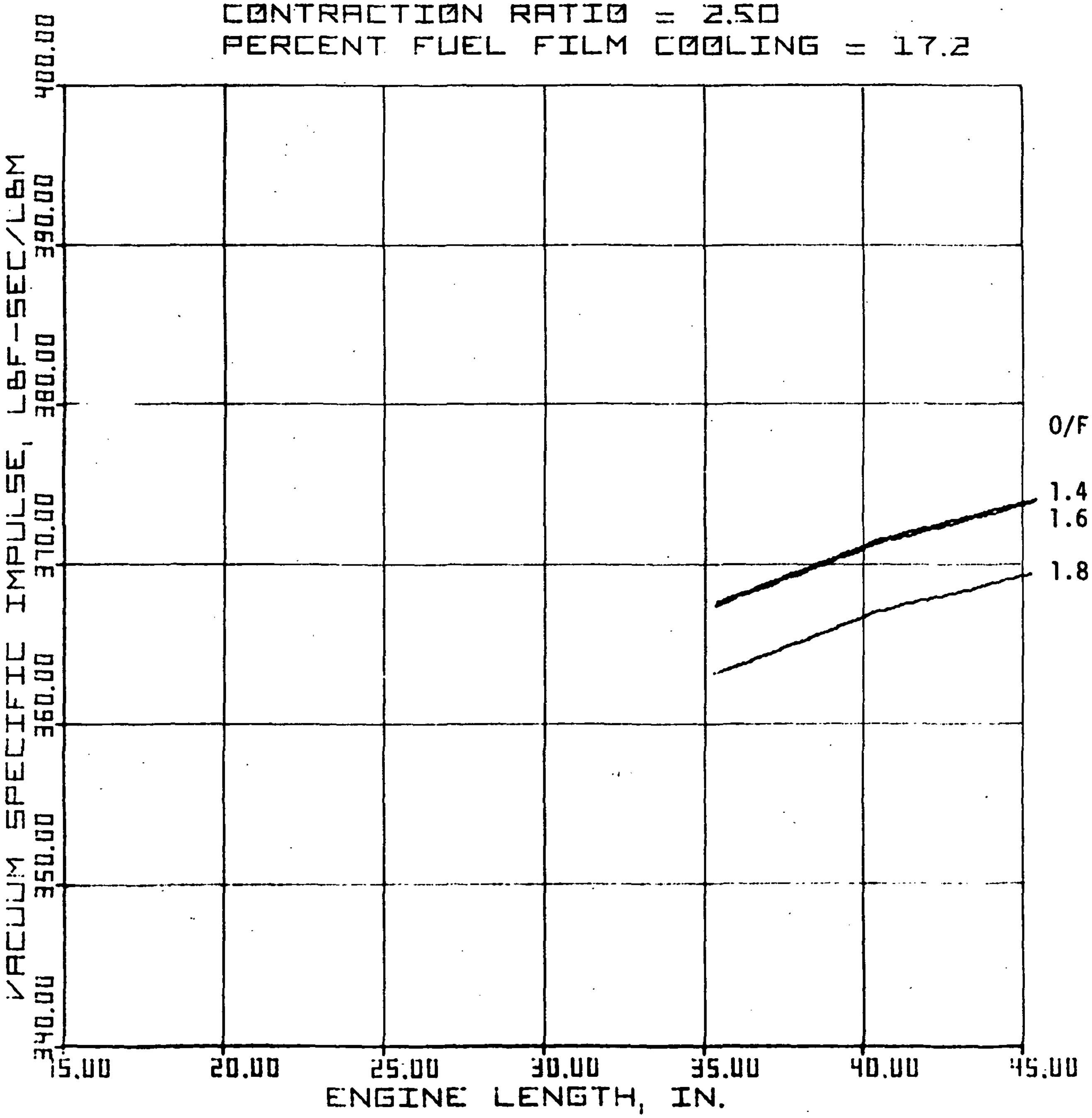
CHAMBER LENGTH = 15.0
CONTRACTION RATIO = 1.50
PERCENT FUEL FILM COOLING = 17.2



FLUORINE/HYDRAZINE ENGINE STUDY

BIMODE ENGINE DATA

CHAMBER PRESSURE = 80.
CHAMBER LENGTH = 15.0
CONTRACTION RATIO = 2.50
PERCENT FUEL FILM COOLING = 17.2



FLUORINE/HYDRAZINE ENGINE STUDY

BIMODE ENGINE DATA

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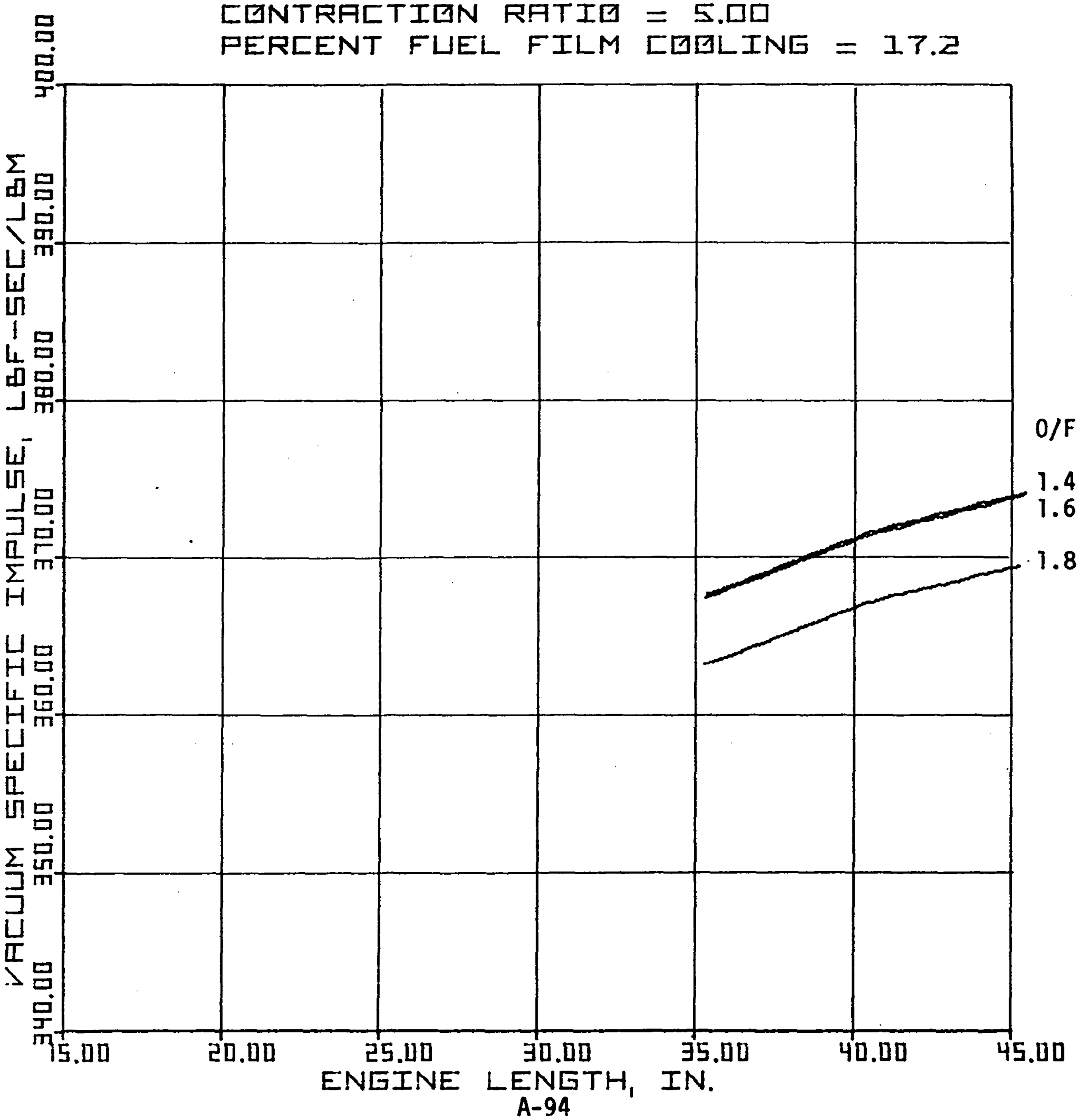
CONTRACTION RATIO = 5.00
PERCENT FUEL FILM COOLING = 17.2



FLUORINE/HYDRAZINE
ENGINE STUDY

BIMODE ENGINE DATA

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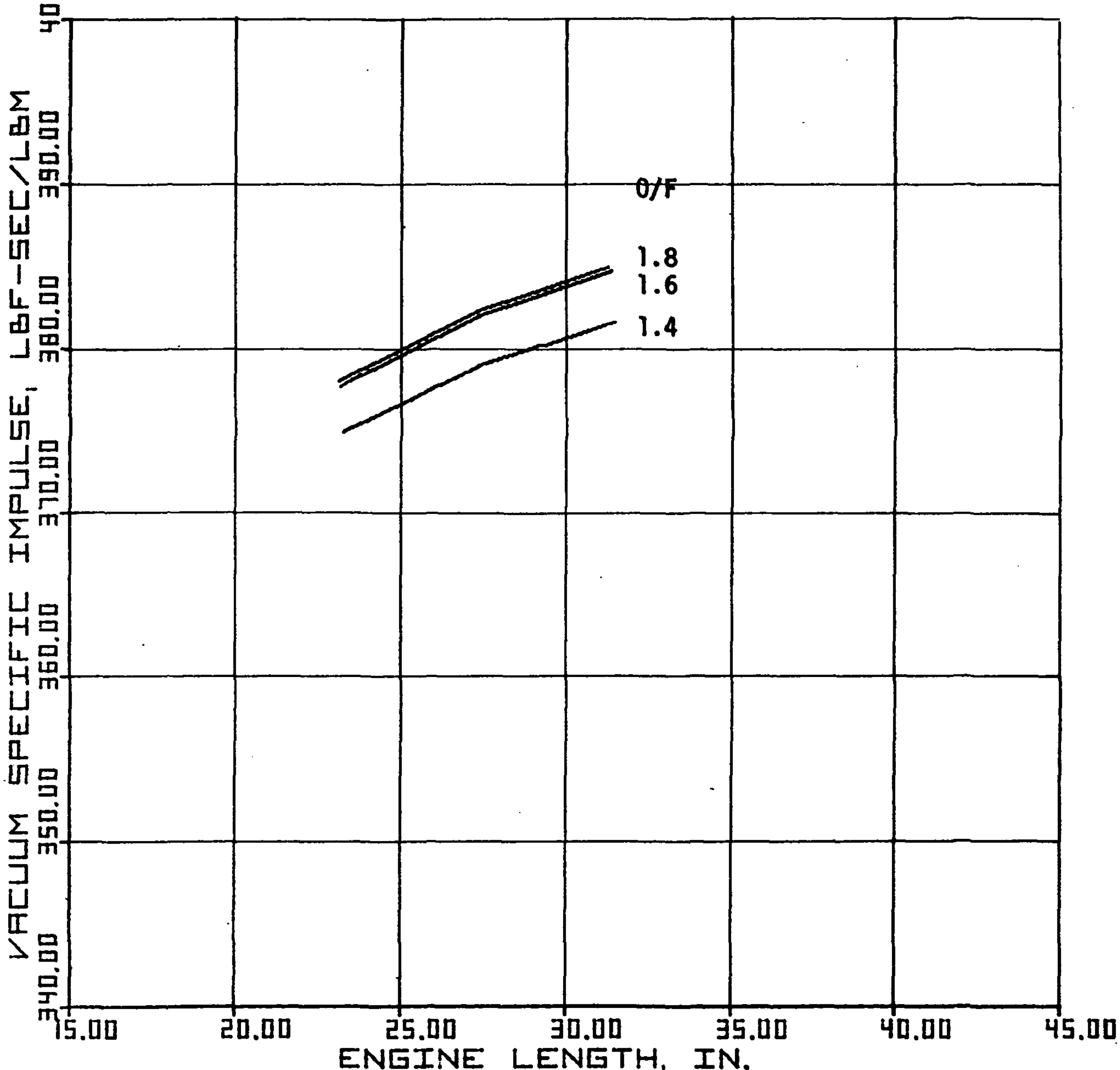
CHAMBER LENGTH = 6.0
CONTRACTION RATIO = 1.50
PERCENT FUEL FILM COOLING = 5.0

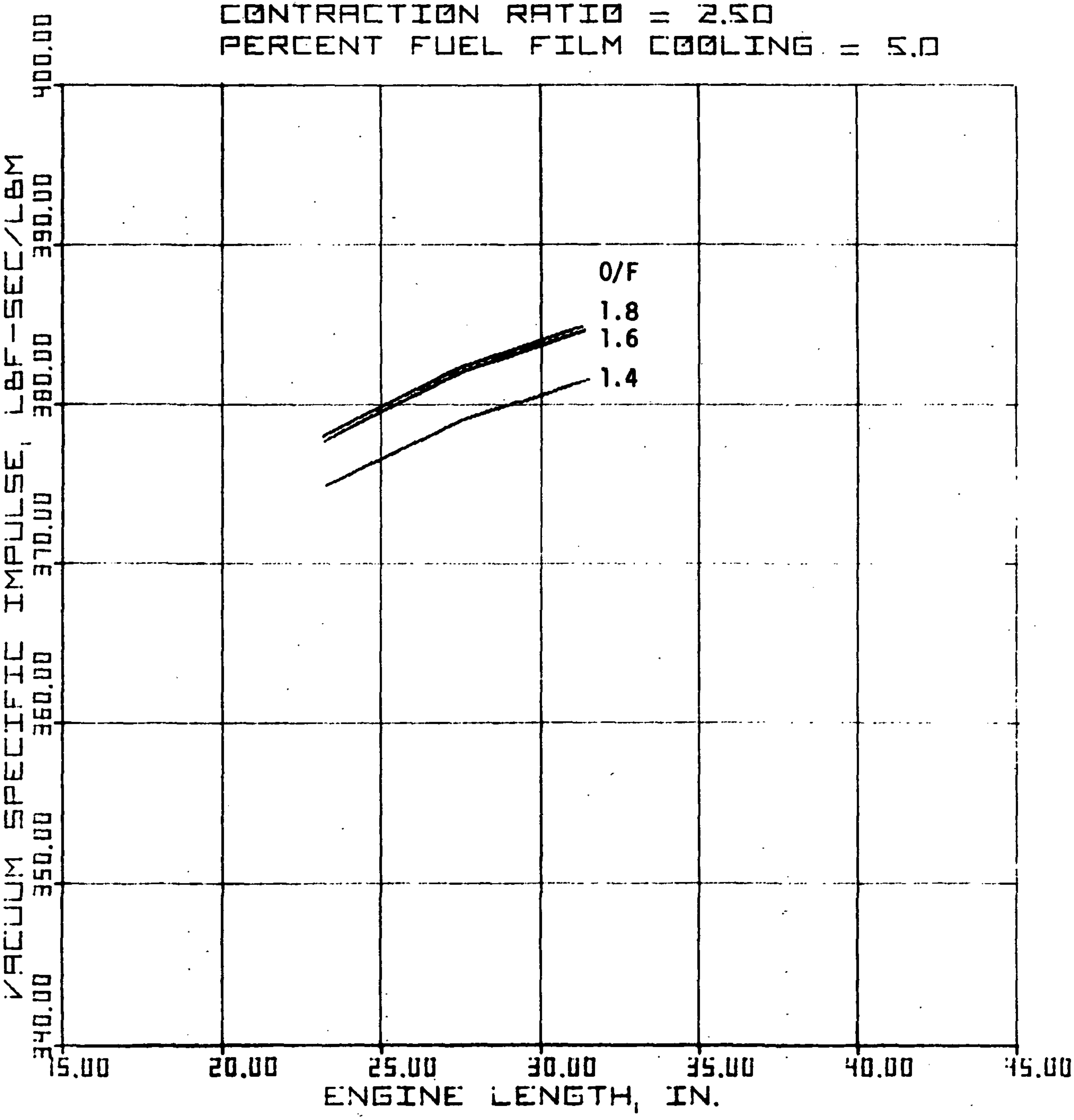


204

FLUORINE/HYDRAZINE ENGINE STUDY

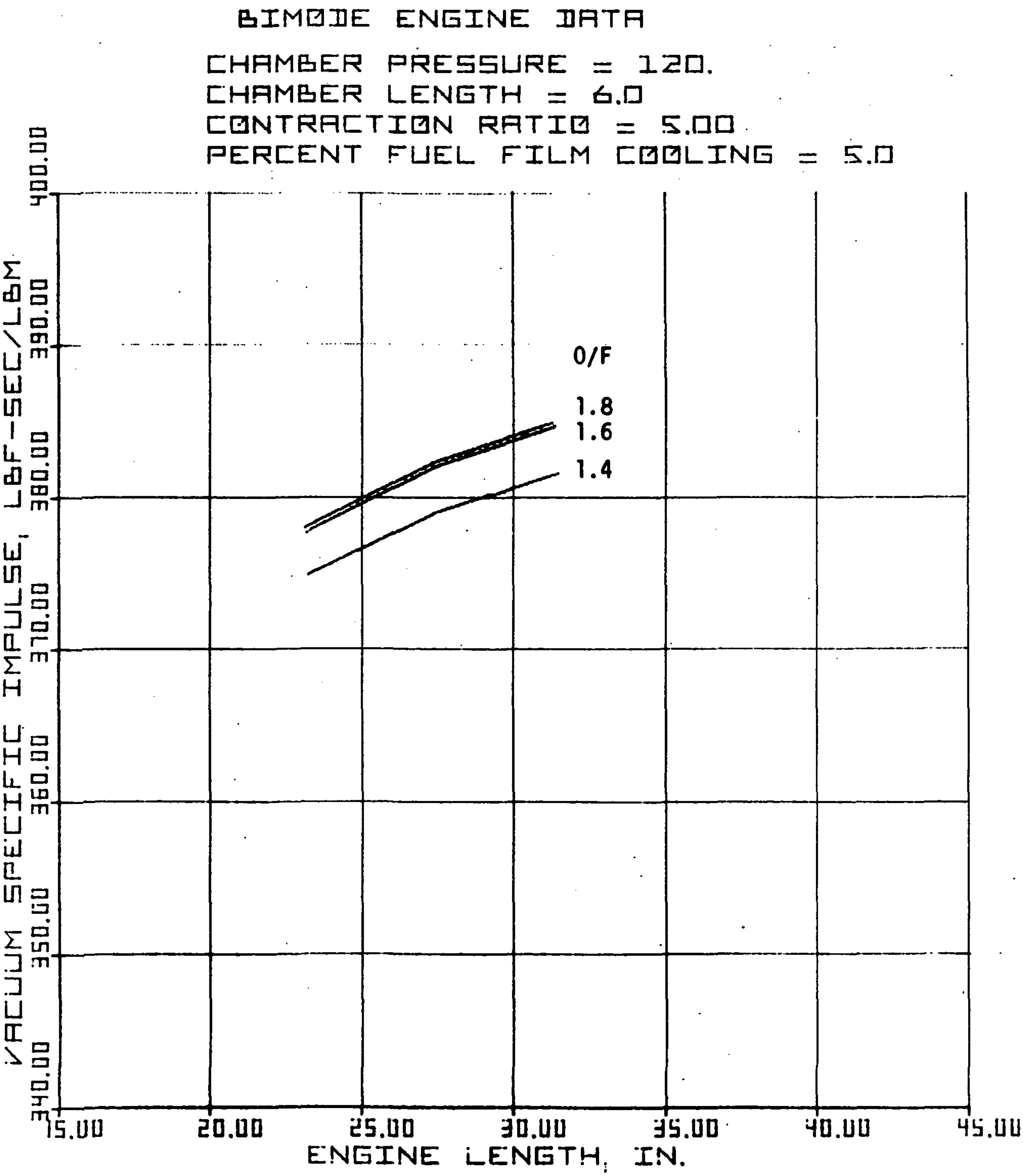
BIMODE ENGINE DATA

CHAMBER PRESSURE = 120.
CHAMBER LENGTH = 6.0
CONTRACTION RATIO = 2.50
PERCENT FUEL FILM COOLING = 5.0



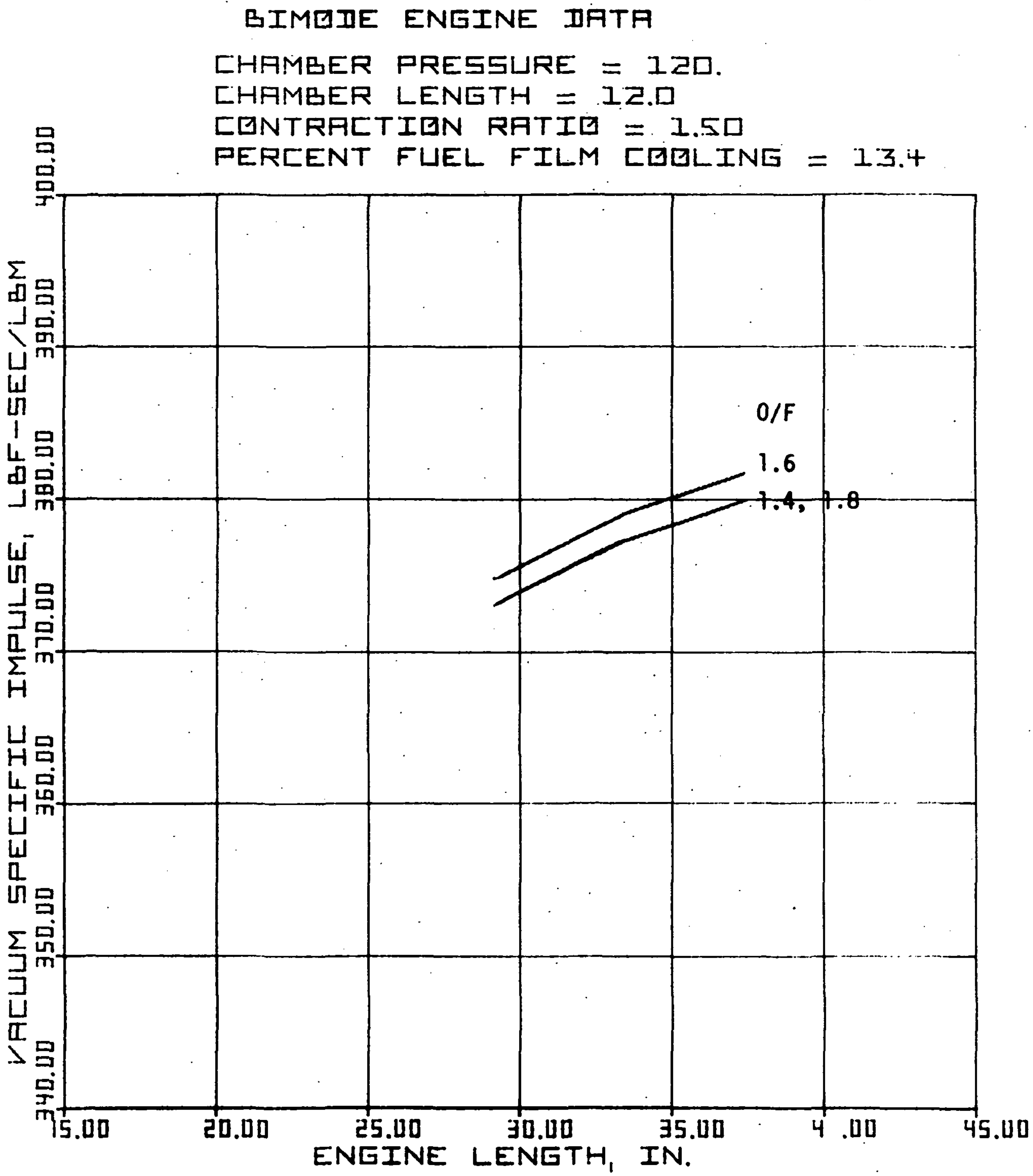
205

FLUORINE/HYDRAZINE ENGINE STUDY



206

FLUORINE/HYDRAZINE ENGINE STUDY

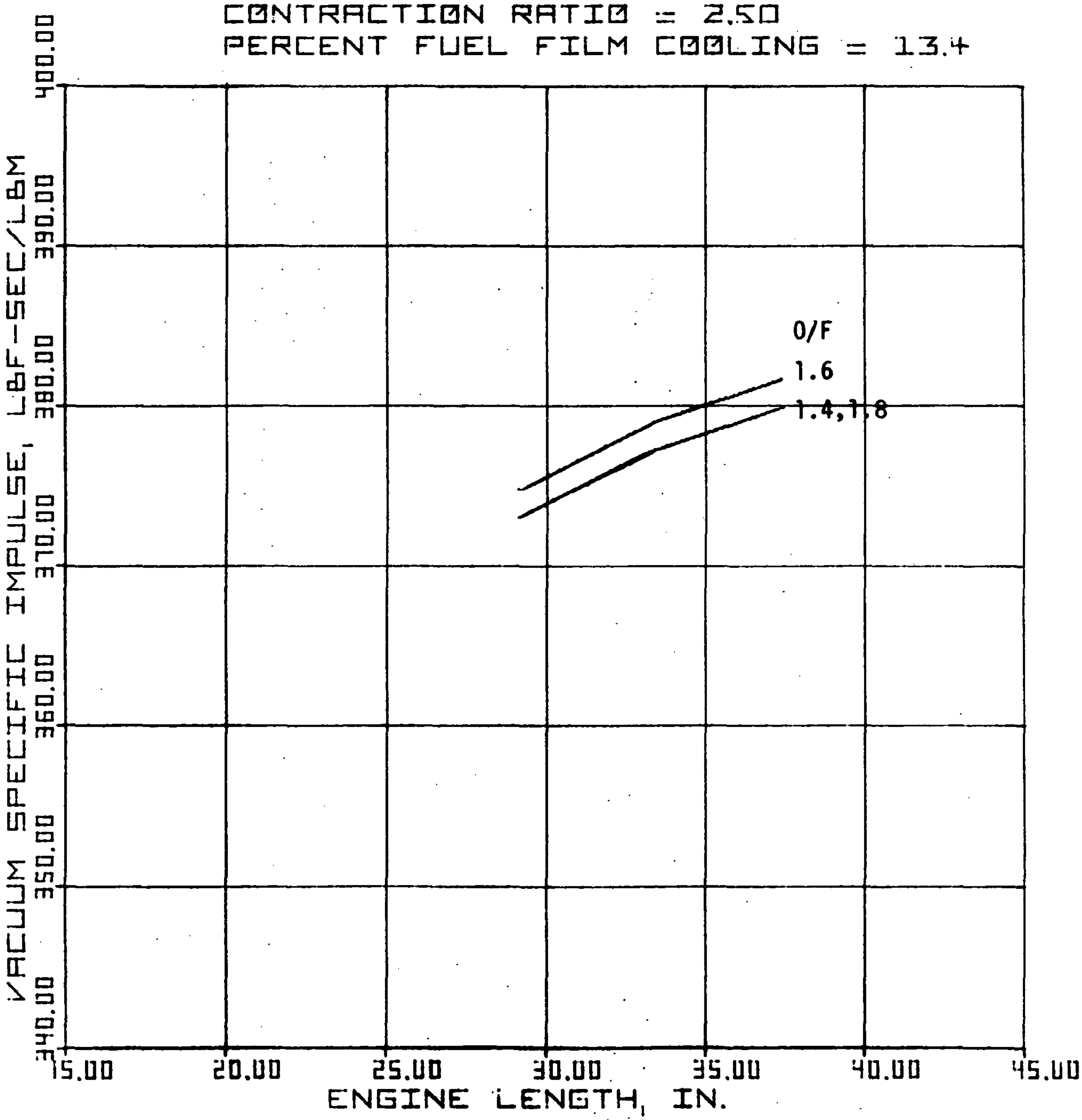


207

FLUORINE/HYDRAZINE ENGINE STUDY

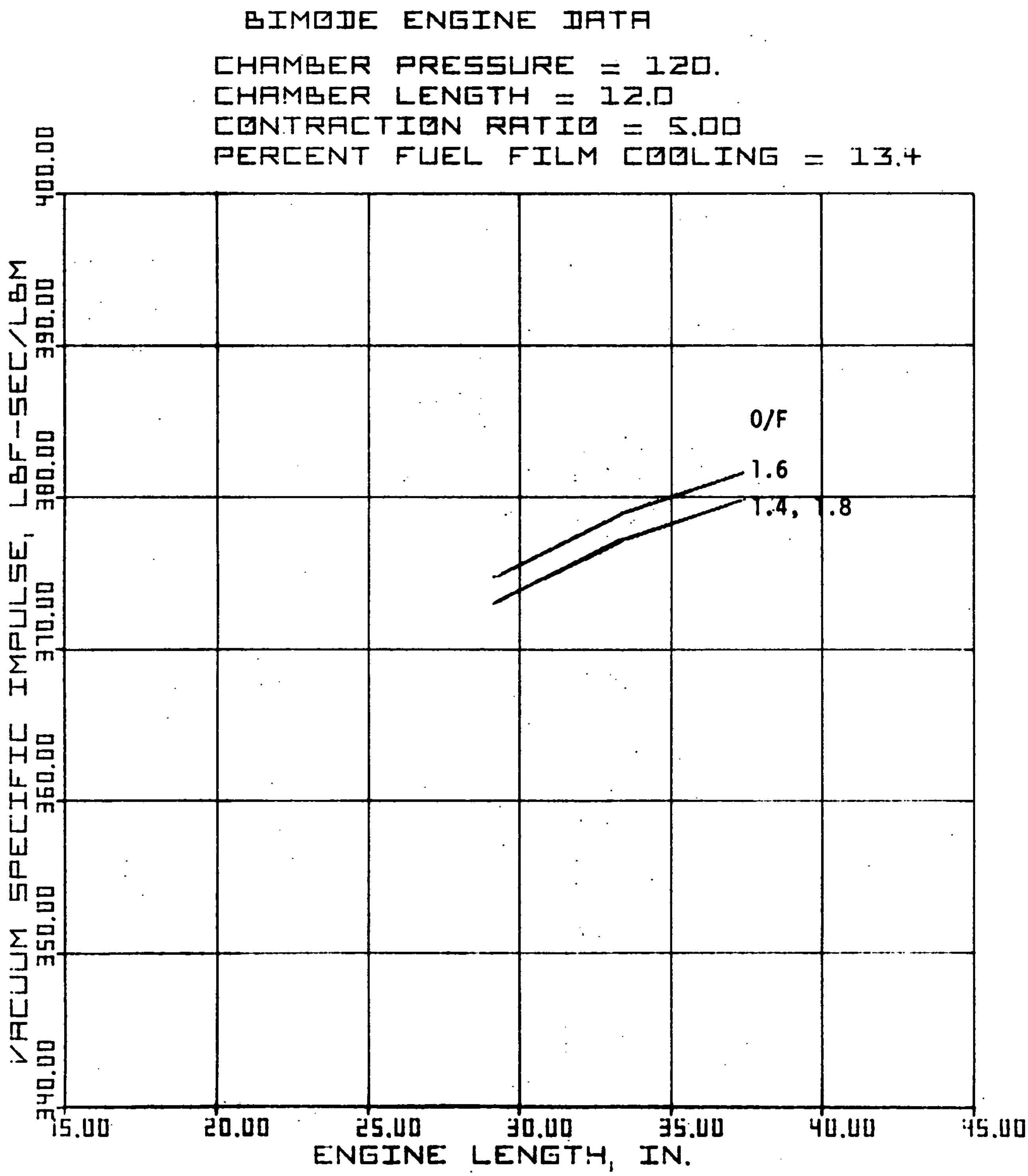
BIMODE ENGINE DATA

CHAMBER PRESSURE = 120.
CHAMBER LENGTH = 12.0
CONTRACTION RATIO = 2.50
PERCENT FUEL FILM COOLING = 13.4



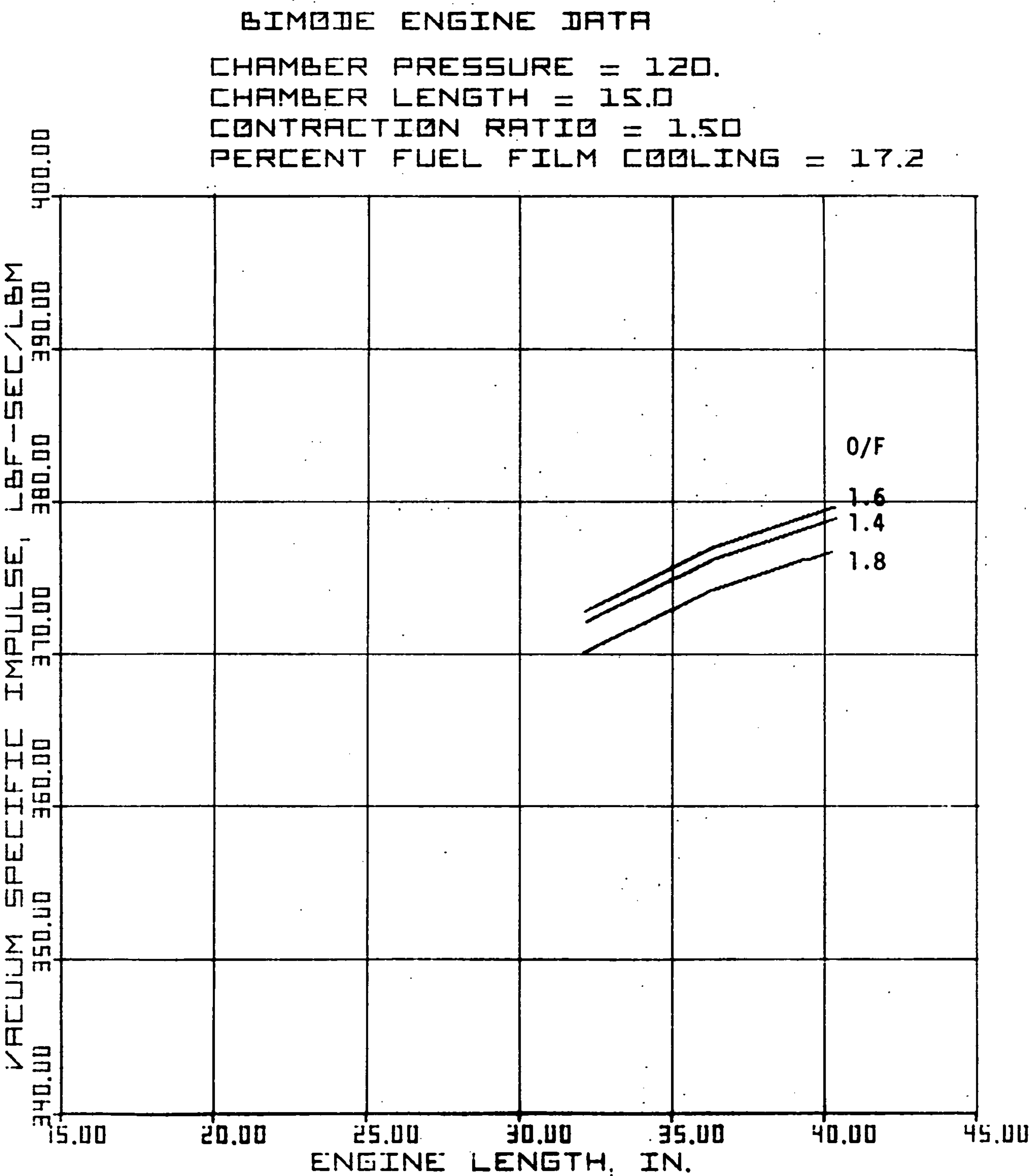
208

FLUORINE/HYDRAZINE ENGINE STUDY



209

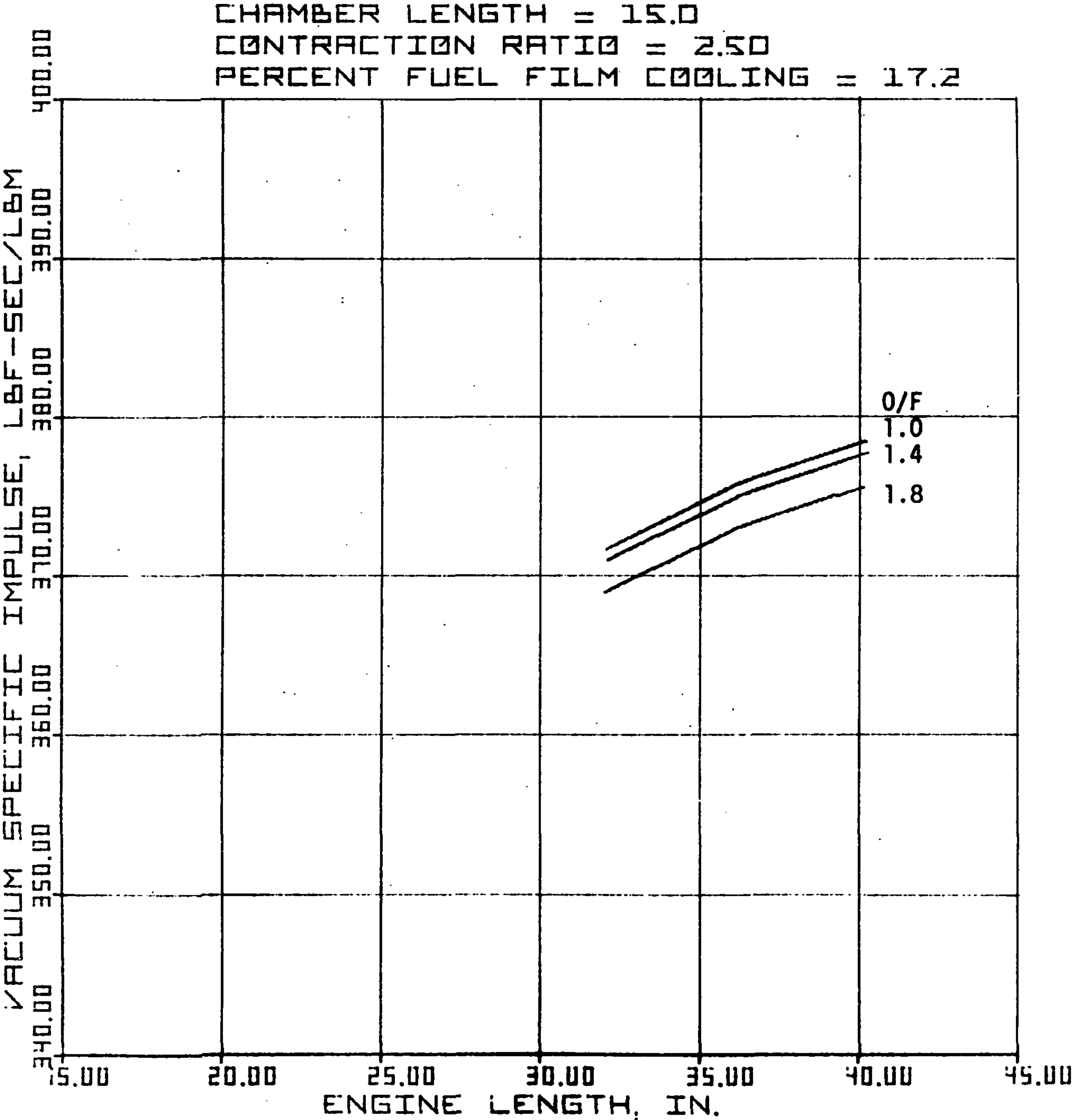
FLUORINE/HYDRAZINE ENGINE STUDY



FLUORINE/HYDRAZINE ENGINE STUDY

BIMODE ENGINE DATA

CHAMBER PRESSURE = 120.
CHAMBER LENGTH = 15.0
CONTRACTION RATIO = 2.50
PERCENT FUEL FILM COOLING = 17.2

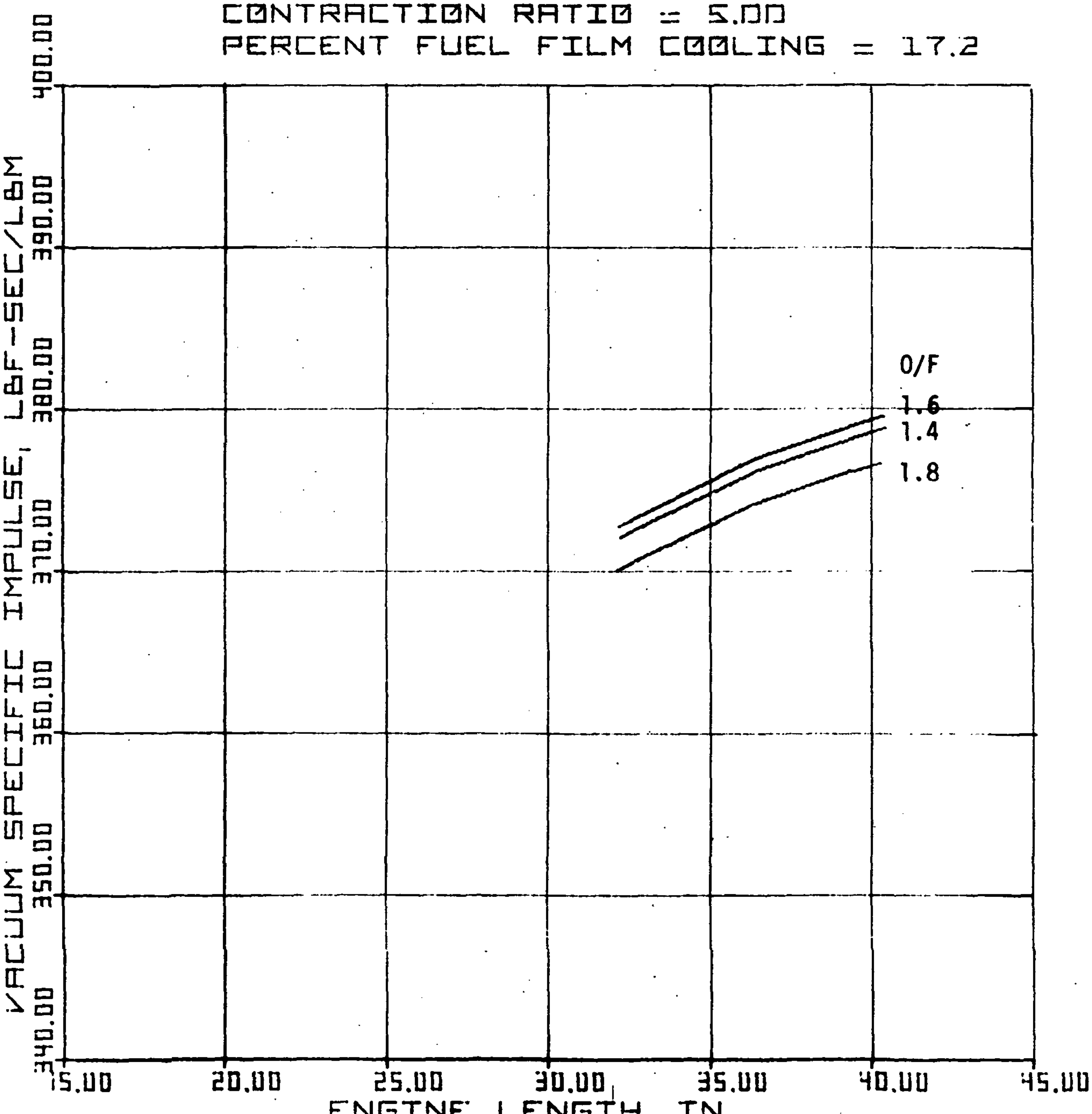


211

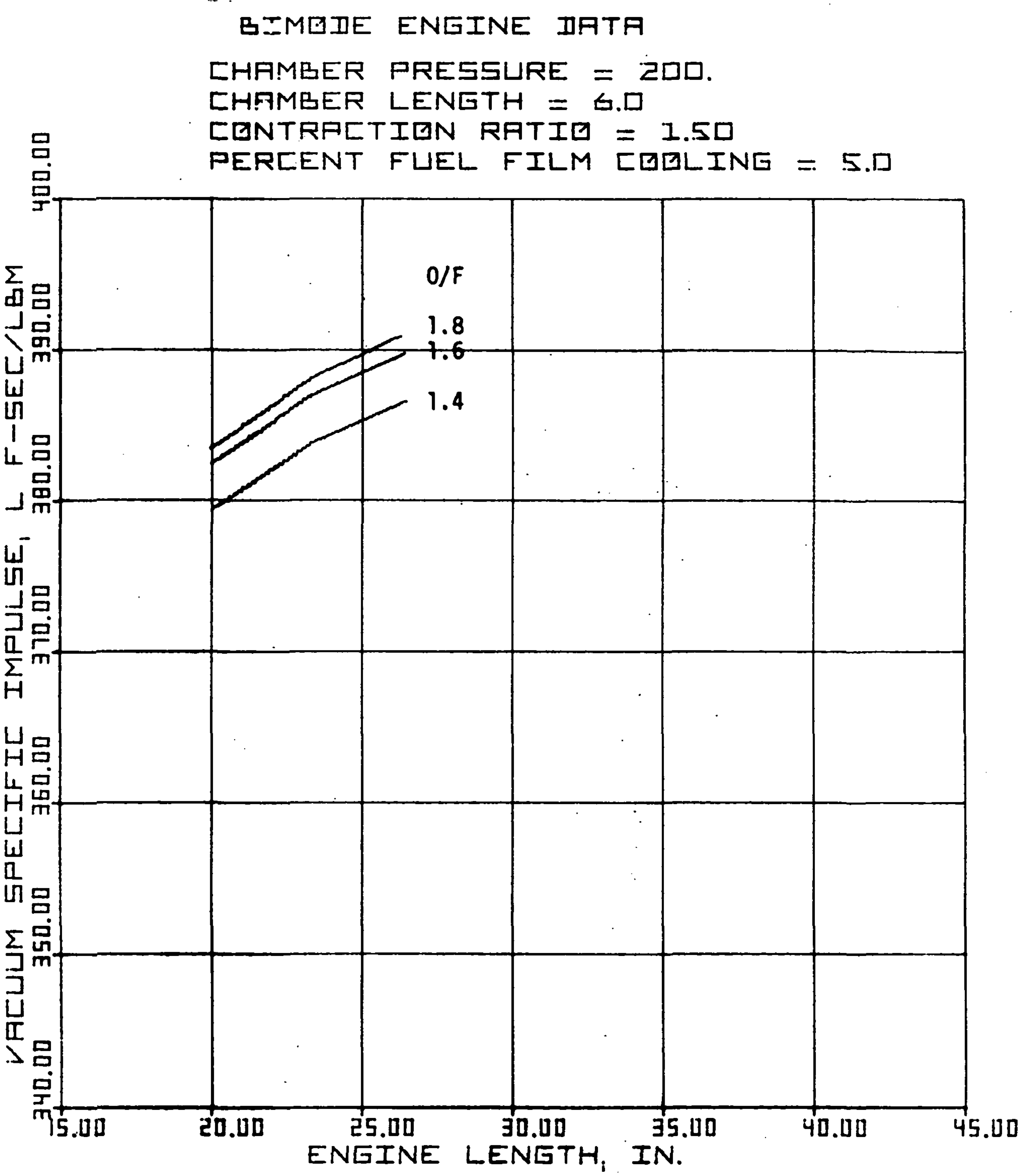
FLUORINE/HYDRAZINE ENGINE STUDY

BIMODE ENGINE DATA

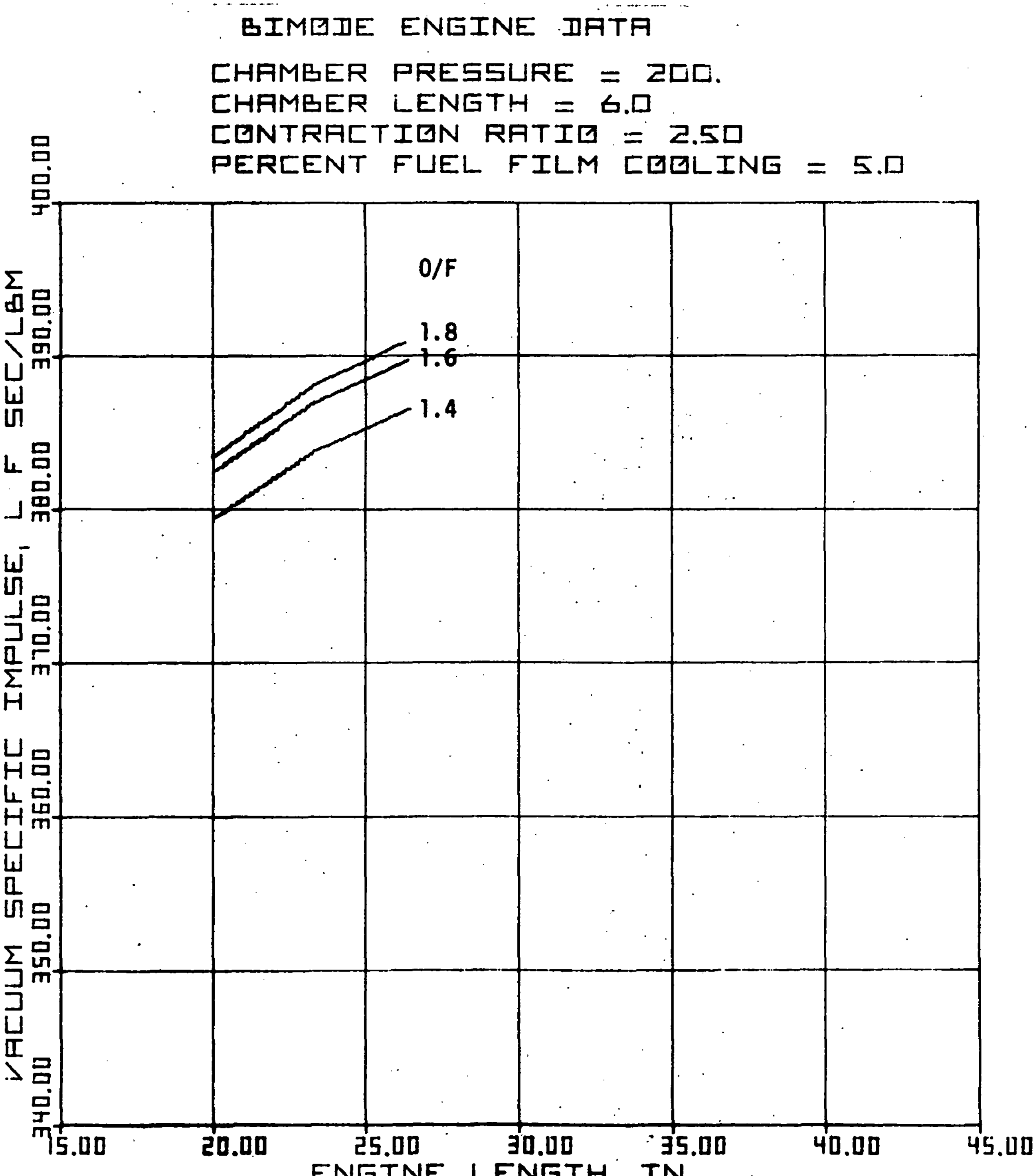
CHAMBER PRESSURE = 120.
CHAMBER LENGTH = 15.0
CONTRACTION RATIO = 5.00
PERCENT FUEL FILM COOLING = 17.2



FLUORINE/HYDRAZINE ENGINE STUDY

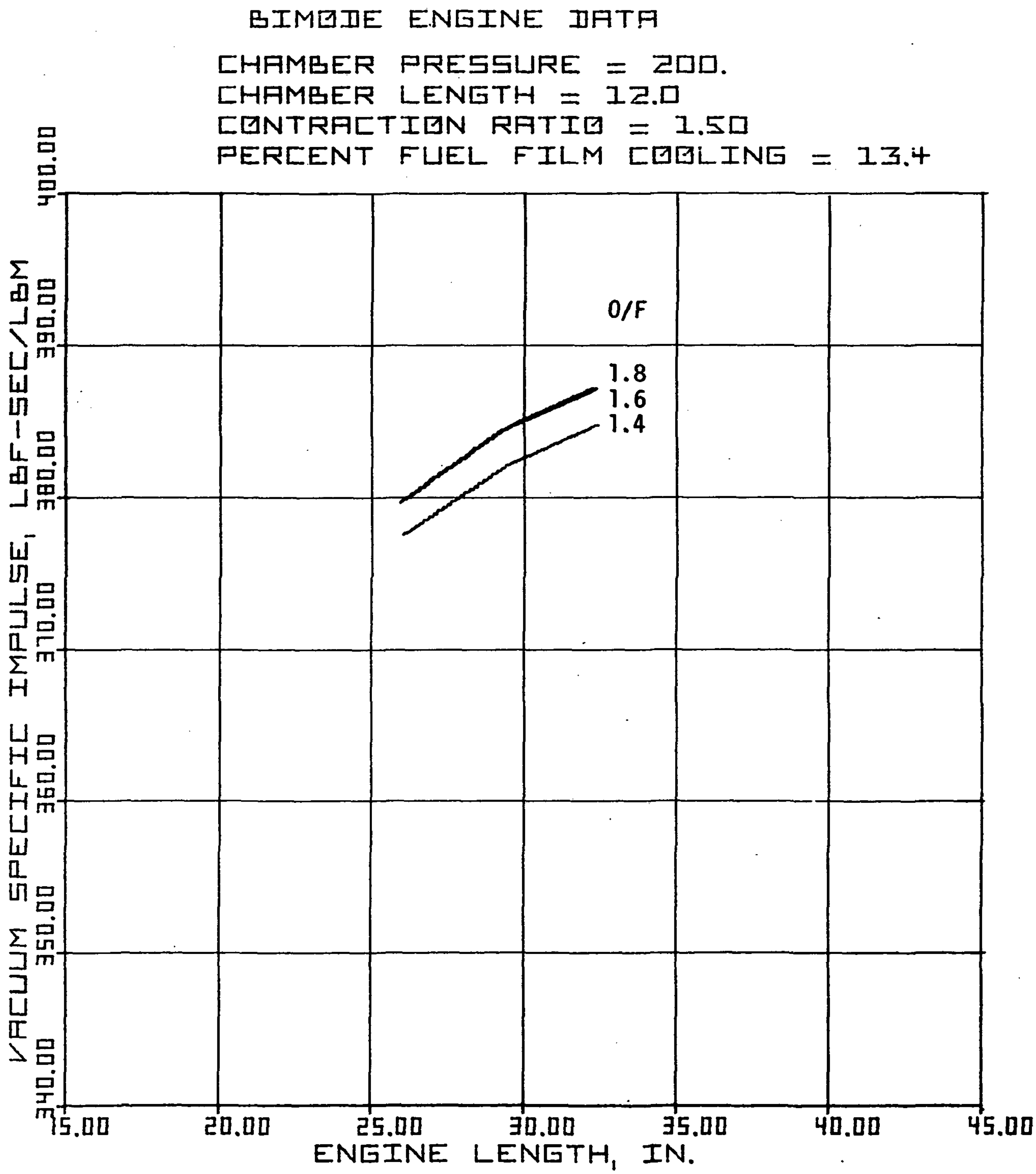


FLUORINE/HYDRAZINE ENGINE STUDY



214

FLUORINE/HYDRAZINE
ENGINE STUDY



FLUORINE/HYDRAZINE ENGINE STUDY

BIMODE ENGINE DATA

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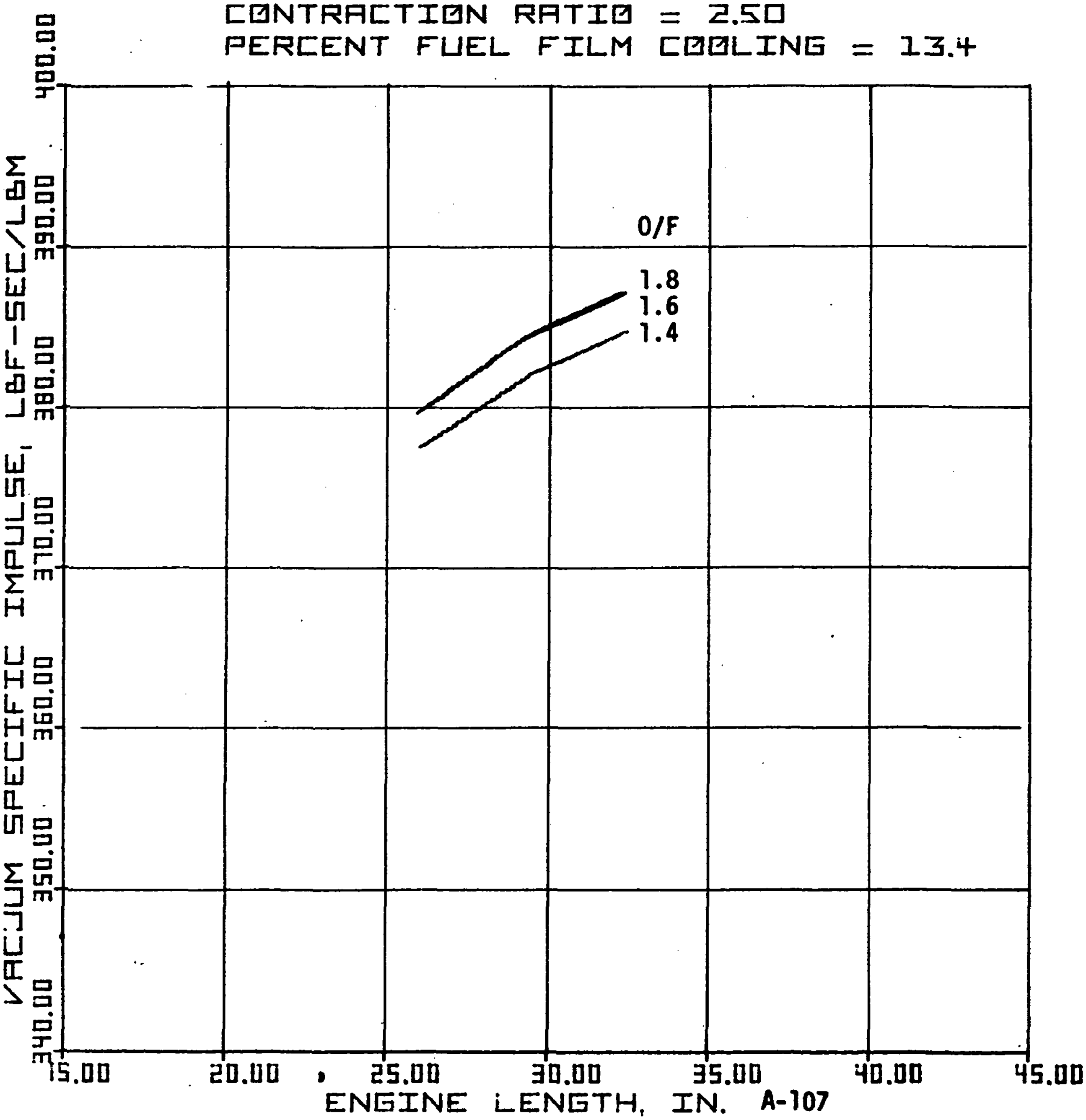
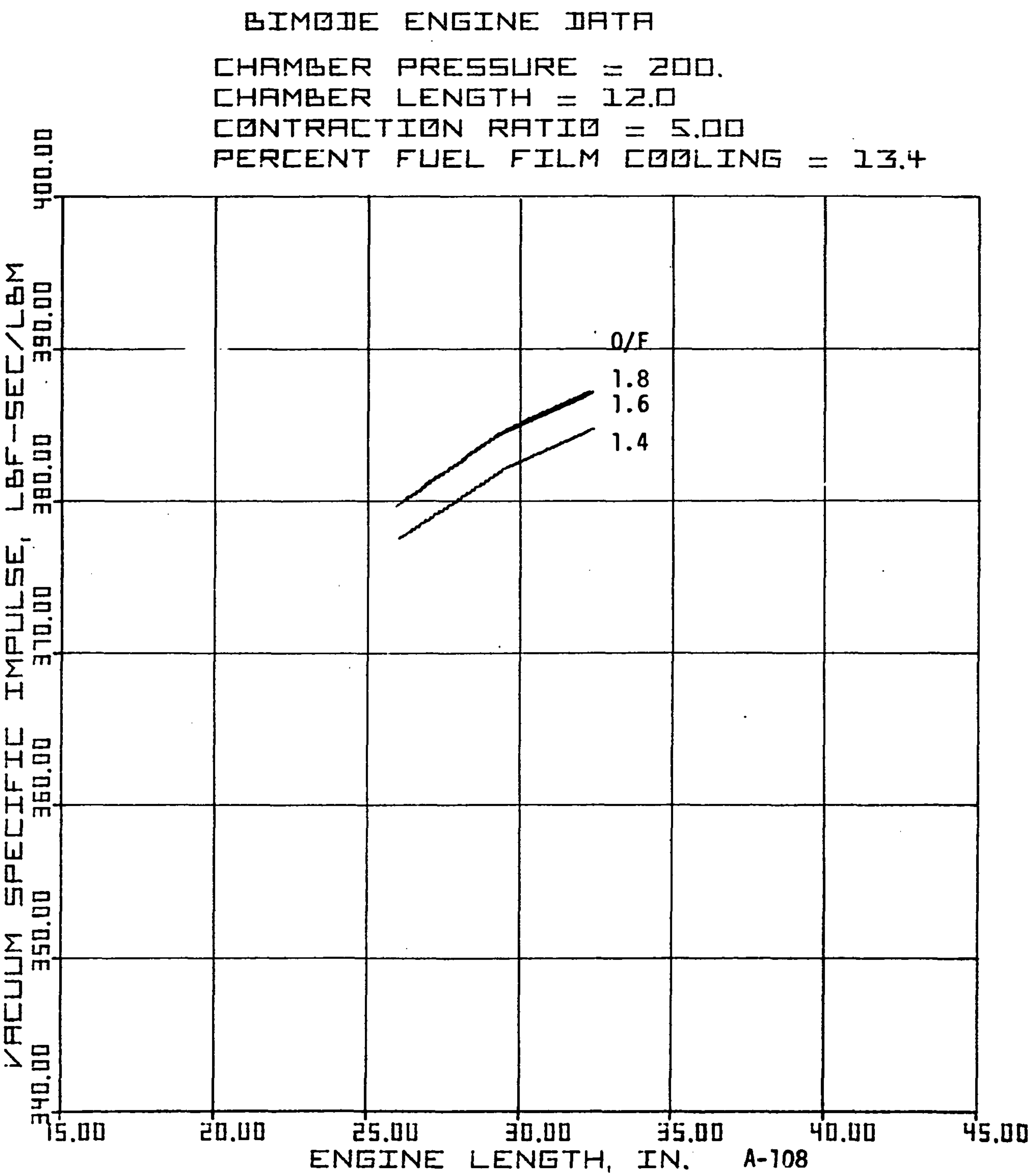
CHAMBER LENGTH = 12.0
CONTRACTION RATIO = 2.50
PERCENT FUEL FILM COOLING = 13.4



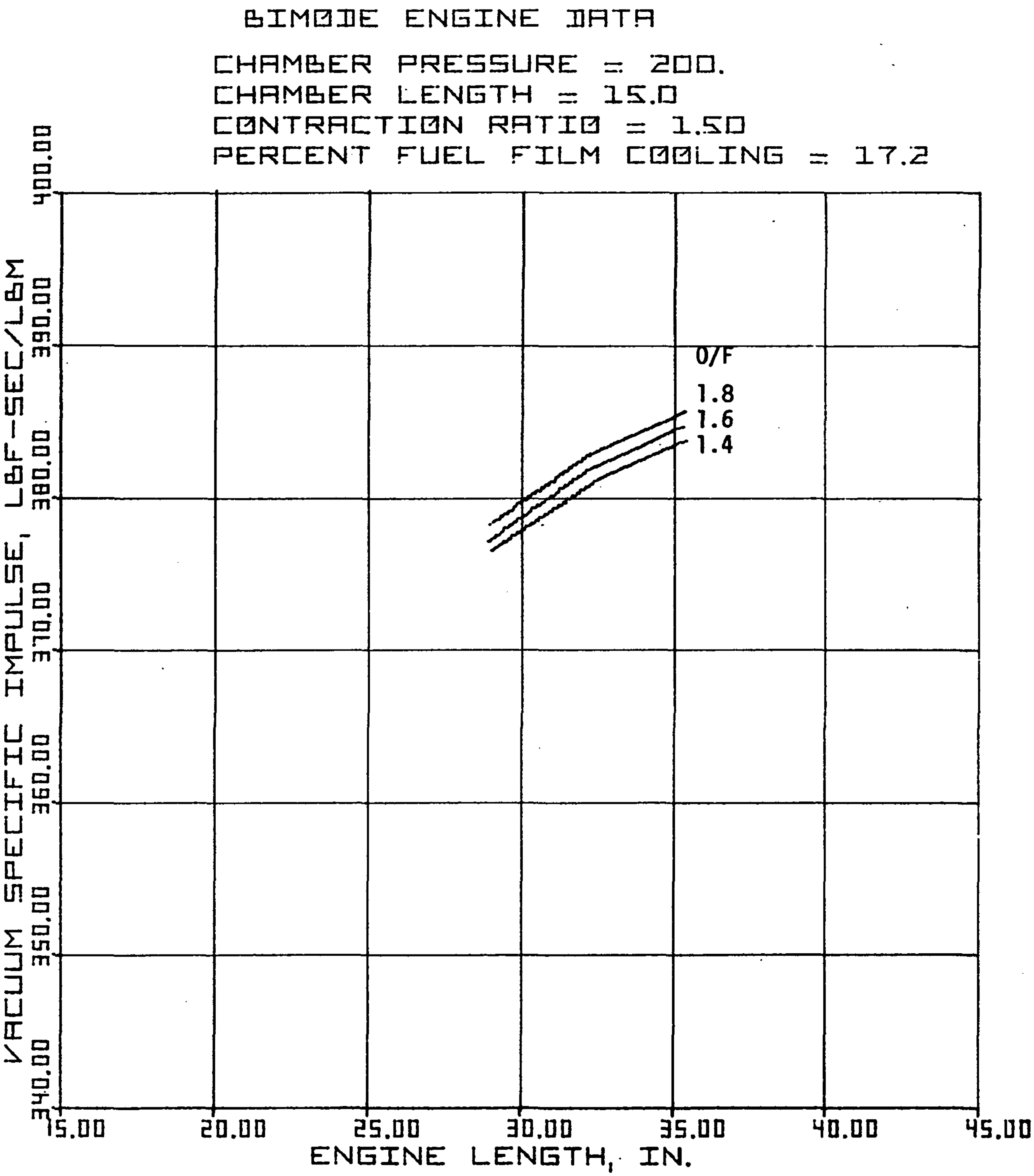
A-107

FLUORINE/HYDRAZINE
ENGINE STUDY

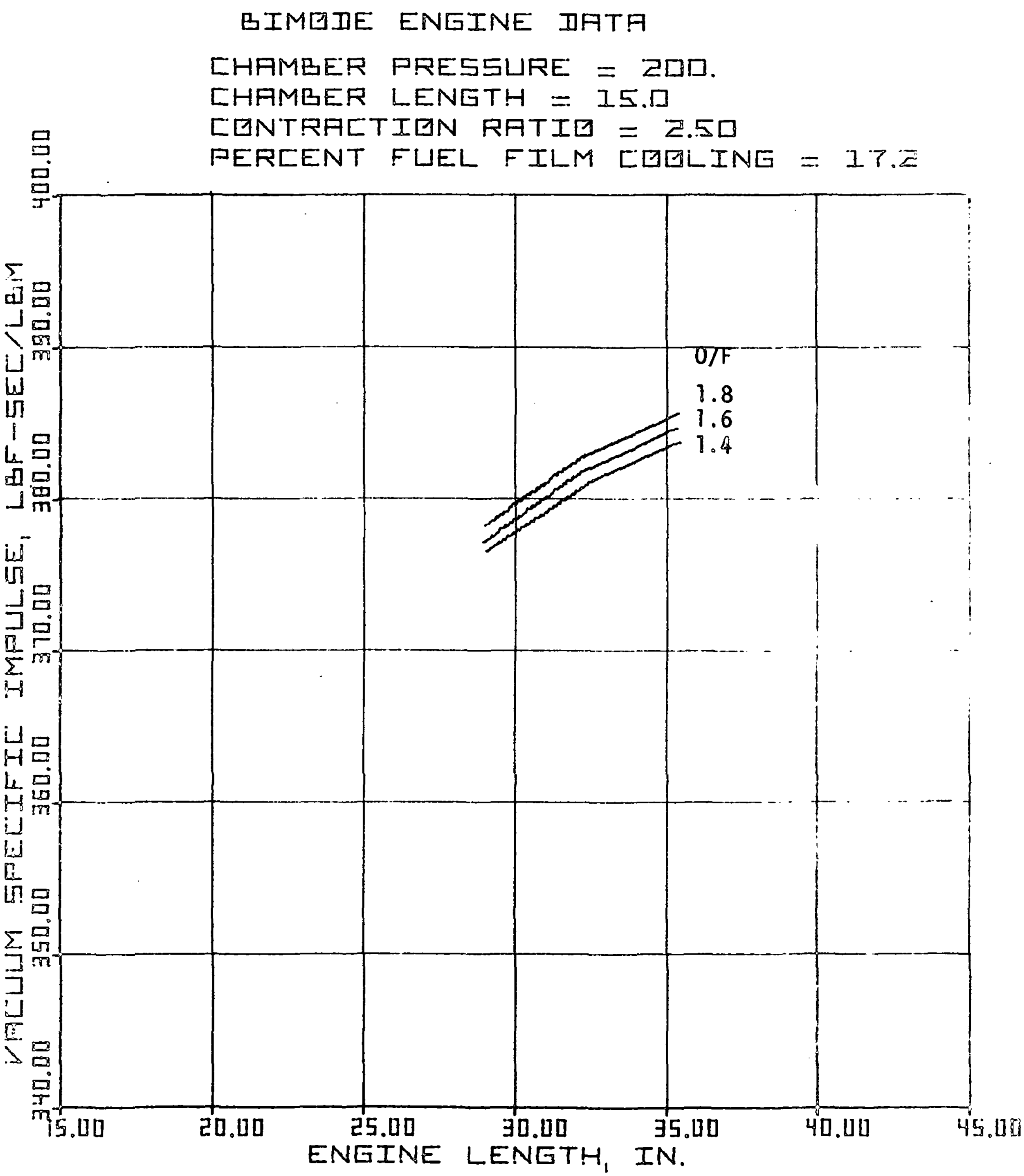


A-108

FLUORINE/HYDRAZINE
ENGINE STUDY

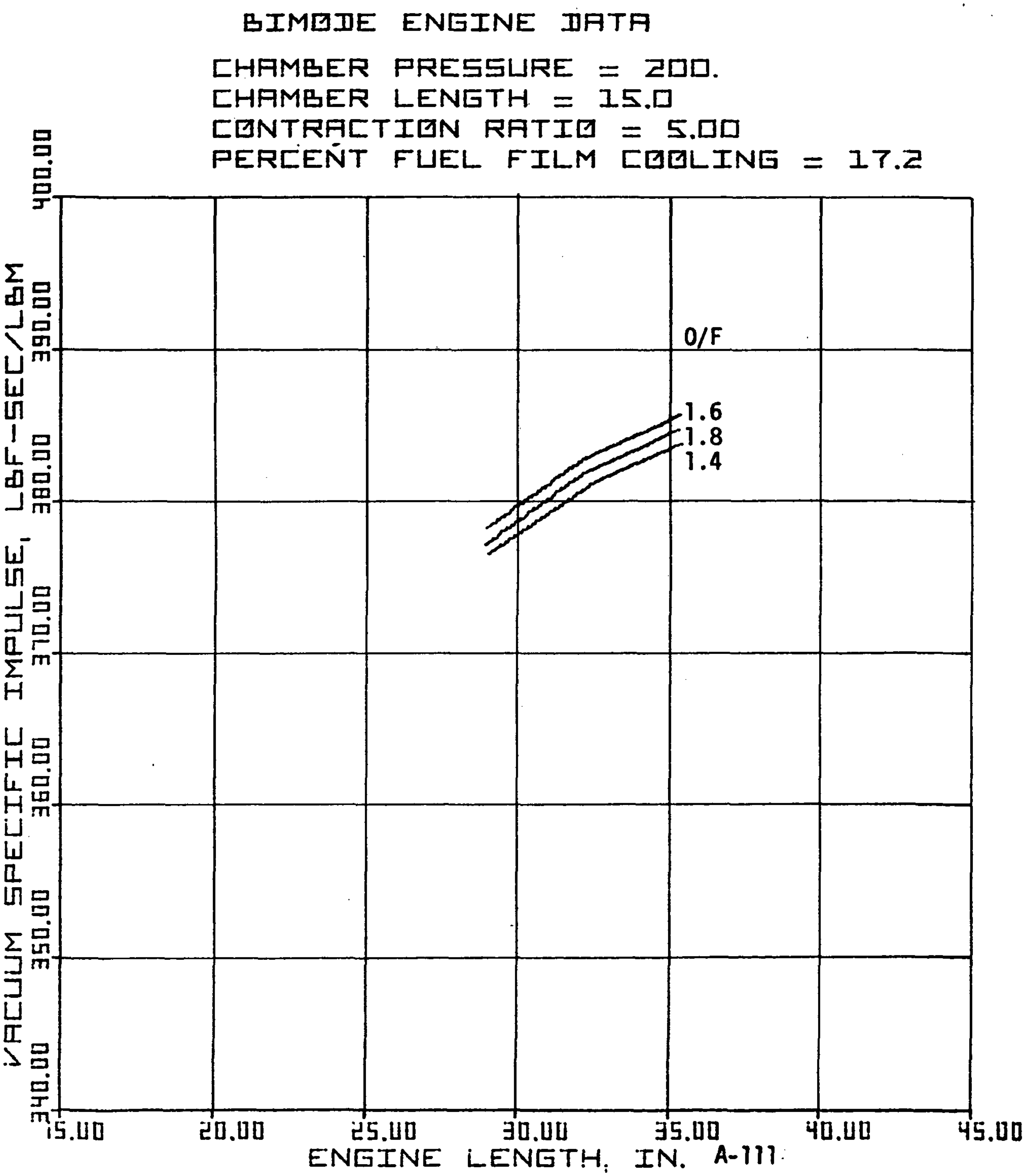


FLUORINE/HYDRAZINE
ENGINE STUDY



219

FLUORINE/HYDRAZINE
ENGINE STUDY



220

APPENDIX A

TABLE SET A

LIQUID-LIQUID ENGINE PERFORMANCE TABULATION

A E R O J E T   L I Q U I D   R O C K E T   C O M P A N Y

FLUORINE/HYDRAZINE ENGINE COMPARISON STUDY

***** LIQUID/LIQUID ENGINE DATA *****

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%ERL	ISPD
600.	80.0	1.40	5.0	40.0	1.50	6.00	17.39	25.39	75.5	1.159	13.9	405.4	5.0	1.1	1.7	.3	4.8	353.2
600.	80.0	1.40	5.0	60.0	1.50	6.00	22.61	30.61	78.0	1.151	14.1	410.8	5.3	1.0	1.8	.3	4.7	357.0
600.	80.0	1.40	5.0	80.0	1.50	6.00	27.47	35.47	80.8	1.147	14.2	414.1	5.5	.8	2.0	.3	4.7	359.4
600.	80.0	1.50	5.0	40.0	1.50	6.00	17.36	25.36	75.5	1.157	14.0	408.7	5.1	1.1	1.7	.2	4.8	355.6
600.	80.0	1.50	5.0	60.0	1.50	6.00	22.56	30.56	78.0	1.149	14.2	414.3	5.5	1.0	1.8	.2	4.8	359.5
600.	80.0	1.50	5.0	80.0	1.50	6.00	27.41	35.41	80.8	1.144	14.3	417.7	5.7	.8	1.9	.2	4.7	361.9
600.	80.0	1.60	5.0	40.0	1.50	6.00	17.33	25.33	75.5	1.155	14.0	411.6	5.2	1.1	1.7	.3	5.0	356.8
600.	80.0	1.60	5.0	60.0	1.50	6.00	22.52	30.52	78.0	1.147	14.2	417.3	5.5	1.0	1.8	.3	5.0	360.6
600.	80.0	1.60	5.0	80.0	1.50	6.00	27.36	35.36	80.8	1.142	14.4	420.9	5.7	.8	1.9	.3	5.0	363.0
600.	80.0	1.70	5.0	40.0	1.50	6.00	17.31	25.31	75.5	1.153	14.1	414.1	5.3	1.1	1.7	.4	5.3	357.1
600.	80.0	1.70	5.0	60.0	1.50	6.00	22.49	30.49	78.0	1.145	14.3	420.0	5.6	.9	1.8	.4	5.2	360.9
600.	80.0	1.70	5.0	80.0	1.50	6.00	27.31	35.31	80.8	1.140	14.4	423.7	5.9	.8	1.9	.4	5.2	363.3
600.	80.0	1.80	5.0	40.0	1.50	6.00	17.28	25.28	75.5	1.151	14.1	416.3	5.5	1.1	1.7	.6	5.3	356.8
600.	80.0	1.80	5.0	60.0	1.50	6.00	22.44	30.44	78.0	1.143	14.3	422.4	5.9	.9	1.8	.6	5.3	360.6
600.	80.0	1.80	5.0	80.0	1.50	6.00	27.26	35.26	80.8	1.138	14.5	426.2	6.1	.8	1.9	.6	5.3	363.0
600.	80.0	1.40	5.0	40.0	2.25	6.00	17.39	25.39	75.5	1.159	9.3	405.4	5.0	1.1	1.7	.3	3.5	358.4
600.	80.0	1.40	5.0	60.0	2.25	6.00	22.61	30.61	78.0	1.151	9.4	410.8	5.3	1.0	1.8	.3	3.5	362.2
600.	80.0	1.40	5.0	80.0	2.25	6.00	27.47	35.47	80.8	1.147	9.5	414.1	5.5	.8	2.0	.3	3.4	364.6
600.	80.0	1.50	5.0	40.0	2.25	6.00	17.36	25.36	75.5	1.157	9.3	408.7	5.1	1.1	1.7	.2	3.4	361.2
600.	80.0	1.50	5.0	60.0	2.25	6.00	22.56	30.56	78.0	1.149	9.5	414.3	5.5	1.0	1.8	.2	3.4	365.1
600.	80.0	1.50	5.0	80.0	2.25	6.00	27.41	35.41	80.8	1.144	9.5	417.7	5.7	.8	1.9	.2	3.4	367.5
600.	80.0	1.60	5.0	40.0	2.25	6.00	17.33	25.33	75.5	1.155	9.4	411.6	5.2	1.1	1.7	.3	3.6	362.6
600.	80.0	1.60	5.0	60.0	2.25	6.00	22.52	30.52	78.0	1.147	9.5	417.3	5.5	1.0	1.8	.3	3.6	366.6
600.	80.0	1.60	5.0	80.0	2.25	6.00	27.36	35.36	80.8	1.142	9.6	420.9	5.7	.8	1.9	.3	3.5	369.0
600.	80.0	1.70	5.0	40.0	2.25	6.00	17.31	25.31	75.5	1.153	9.8	414.1	5.3	1.1	1.7	.4	3.9	362.5
600.	80.0	1.70	5.0	60.0	2.25	6.00	22.49	30.49	78.0	1.145	10.0	420.0	5.6	1.0	1.8	.4	3.9	366.4
600.	80.0	1.70	5.0	80.0	2.25	6.00	27.31	35.31	80.8	1.140	10.1	423.7	5.9	.8	1.9	.4	3.9	368.8
600.	80.0	1.80	5.0	40.0	2.25	6.00	17.28	25.28	75.5	1.151	10.2	416.3	5.5	1.1	1.7	.6	4.2	361.6
600.	80.0	1.80	5.0	60.0	2.25	6.00	22.44	30.44	78.0	1.143	10.4	422.4	5.9	1.0	1.8	.6	4.2	365.4
600.	80.0	1.80	5.0	80.0	2.25	6.00	27.26	35.26	80.8	1.138	10.5	426.2	6.1	.8	1.9	.6	4.2	367.8
600.	80.0	1.40	5.0	40.0	5.00	6.00	17.39	25.39	75.5	1.159	8.6	405.4	5.0	1.1	1.7	.3	3.7	357.8
600.	80.0	1.40	5.0	60.0	5.00	6.00	22.61	30.61	78.0	1.151	8.7	410.8	5.3	1.0	1.8	.3	3.6	361.6
600.	80.0	1.40	5.0	80.0	5.00	6.00	27.47	35.47	80.8	1.147	8.7	414.1	5.5	.8	2.0	.3	3.6	364.0
600.	80.0	1.50	5.0	40.0	5.00	6.00	17.36	25.36	75.5	1.157	9.0	408.7	5.1	1.1	1.7	.2	3.6	359.9
600.	60.0	1.50	5.0	60.0	5.00	6.00	22.56	30.56	78.0	1.149	9.1	414.3	5.5	1.0	1.8	.2	3.7	363.8
600.	80.0	1.50	5.0	60.0	5.00	6.00	27.41	35.41	80.8	1.144	9.2	417.7	5.7	.8	1.9	.2	3.7	366.2
600.	80.0	1.60	5.0	40.0	5.00	6.00	17.33	25.33	75.5	1.155	9.4	411.6	5.2	1.1	1.7	.3	4.1	360.6
600.	80.0	1.60	5.0	60.0	5.00	6.00	22.52	30.52	78.0	1.147	9.5	417.3	5.5	1.0	1.8	.3	4.1	364.5

ENGLISH UNIτS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD
600.	80.0	1.60	5.0	80.0	5.00	6.00	27.36	35.36	80.8	1.142	9.6	420.9	5.7	.8	1.9	.3	4.0	366.9
600.	80.0	1.70	5.0	40.0	5.00	6.00	17.31	25.31	75.5	1.153	9.8	414.1	5.3	1.1	1.7	.4	4.5	360.3
600.	80.0	1.70	5.0	60.0	5.00	6.00	22.49	30.49	78.0	1.145	10.0	420.0	5.6	1.0	1.8	.4	4.5	364.1
600.	80.0	1.70	5.0	80.0	5.00	6.00	27.31	35.31	80.8	1.140	10.1	423.7	5.9	.8	1.9	.4	4.5	366.5
600.	80.0	1.80	5.0	40.0	5.00	6.00	17.28	25.28	75.5	1.151	10.2	416.3	5.5	1.1	1.7	.6	4.7	359.3
600.	80.0	1.80	5.0	60.0	5.00	6.00	22.44	30.44	78.0	1.143	10.4	422.4	5.9	.9	1.8	.6	4.7	363.1
600.	80.0	1.80	5.0	80.0	5.00	6.00	27.26	35.26	80.8	1.138	10.5	426.2	6.1	.8	1.9	.6	4.7	365.5
600.	80.0	1.40	13.4	40.0	1.50	12.00	17.39	31.39	75.5	1.159	13.9	405.4	5.0	1.2	1.7	.7	1.5	364.7
600.	80.0	1.40	13.4	60.0	1.50	12.00	22.61	36.61	78.0	1.151	14.1	410.8	5.3	1.0	1.8	.7	1.5	368.7
600.	80.0	1.40	13.4	80.0	1.50	12.00	27.47	41.47	80.8	1.147	14.2	414.1	5.5	.9	2.0	.6	1.5	371.1
600.	80.0	1.50	13.4	40.0	1.50	12.00	17.36	31.36	75.5	1.157	14.0	408.7	5.1	1.2	1.7	.8	1.5	366.7
600.	80.0	1.50	13.4	60.0	1.50	12.00	22.56	36.56	78.0	1.149	14.2	414.3	5.5	1.0	1.8	.7	1.5	370.7
600.	80.0	1.50	13.4	80.0	1.50	12.00	27.41	41.41	80.8	1.144	14.3	417.7	5.7	.8	1.9	.7	1.5	373.2
600.	80.0	1.60	13.4	40.0	1.50	12.00	17.33	31.33	75.5	1.155	14.0	411.6	5.2	1.2	1.7	1.1	1.6	367.4
600.	80.0	1.60	13.4	60.0	1.50	12.00	22.52	36.52	78.0	1.147	14.2	417.3	5.5	1.0	1.8	1.1	1.6	371.4
600.	80.0	1.60	13.4	80.0	1.50	12.00	27.36	41.36	80.8	1.142	14.4	420.9	5.7	.8	1.9	1.0	1.6	373.9
600.	80.0	1.70	13.4	40.0	1.50	12.00	17.31	31.31	75.5	1.153	14.1	414.1	5.3	1.1	1.7	1.6	1.6	367.1
600.	80.0	1.70	13.4	60.0	1.50	12.00	22.49	36.49	78.0	1.145	14.3	420.0	5.6	1.0	1.8	1.6	1.6	371.1
600.	80.0	1.70	13.4	80.0	1.50	12.00	27.31	41.31	80.8	1.140	14.4	423.7	5.9	.8	1.9	1.6	1.6	373.5
600.	80.0	1.80	13.4	40.0	1.50	12.00	17.28	31.28	75.5	1.151	14.1	416.3	5.5	1.1	1.7	2.1	1.6	366.2
600.	80.0	1.80	13.4	60.0	1.50	12.00	22.44	36.44	78.0	1.143	14.3	422.4	5.9	1.0	1.8	2.1	1.6	370.1
600.	80.0	1.80	13.4	80.0	1.50	12.00	27.26	41.26	80.8	1.138	14.5	426.2	6.1	.8	1.9	2.1	1.6	372.5
600.	80.0	1.40	13.4	40.0	2.25	12.00	17.39	31.39	75.5	1.159	9.4	405.4	5.0	1.2	1.7	.7	1.1	366.4
600.	80.0	1.40	13.4	60.0	2.25	12.00	22.61	36.61	78.0	1.151	9.5	410.8	5.3	1.0	1.8	.7	1.1	370.3
600.	80.0	1.40	13.4	80.0	2.25	12.00	27.47	41.47	80.8	1.147	9.6	414.1	5.5	.9	2.0	.6	1.0	372.8
600.	80.0	1.50	13.4	40.0	2.25	12.00	17.36	31.36	75.5	1.157	9.9	408.7	5.1	1.2	1.7	.8	1.2	368.2
600.	80.0	1.50	13.4	60.0	2.25	12.00	22.56	36.56	78.0	1.149	10.0	414.3	5.5	1.0	1.8	.7	1.1	372.2
600.	80.0	1.50	13.4	80.0	2.25	12.00	27.41	41.41	80.8	1.144	10.1	417.7	5.7	.9	1.9	.7	1.1	374.7
600.	80.0	1.60	13.4	40.0	2.25	12.00	17.33	31.33	75.5	1.155	10.3	411.6	5.2	1.2	1.7	1.1	1.3	369.6
600.	80.0	1.60	13.4	60.0	2.25	12.00	22.52	36.52	78.0	1.147	10.5	417.3	5.5	1.0	1.8	1.1	1.3	372.7
600.	80.0	1.60	13.4	80.0	2.25	12.00	27.36	41.36	80.8	1.142	10.6	420.9	5.7	.8	1.9	1.0	1.3	375.2
600.	80.0	1.70	13.4	40.0	2.25	12.00	17.31	31.31	75.5	1.153	10.8	414.1	5.3	1.1	1.7	1.6	1.4	368.1
600.	80.0	1.70	13.4	60.0	2.25	12.00	22.49	36.49	78.0	1.145	10.9	420.0	5.6	1.0	1.8	1.6	1.4	372.0
600.	80.0	1.70	13.4	80.0	2.25	12.00	27.31	41.31	80.8	1.140	11.0	423.7	5.9	.8	1.9	1.6	1.4	374.5
600.	80.0	1.80	13.4	40.0	2.25	12.00	17.28	31.28	75.5	1.151	11.2	416.3	5.5	1.1	1.7	2.1	1.4	366.8
600.	80.0	1.80	13.4	60.0	2.25	12.00	22.44	36.44	78.0	1.143	11.4	422.4	5.9	1.0	1.8	2.1	1.4	370.8
600.	80.0	1.80	13.4	80.0	2.25	12.00	27.26	41.26	80.8	1.138	11.5	426.2	6.1	.8	1.9	2.1	1.4	373.2
600.	80.0	1.40	13.4	40.0	5.00	12.00	17.39	31.39	75.5	1.159	9.4	405.4	5.0	1.2	1.7	.7	1.6	364.3
600.	80.0	1.40	13.4	60.0	5.00	12.00	22.61	36.61	78.0	1.151	9.5	410.8	5.3	1.0	1.8	.7	1.6	368.2
600.	80.0	1.40	13.4	80.0	5.00	12.00	27.47	41.47	80.8	1.147	9.6	414.1	5.5	.9	2.0	.6	1.6	370.7

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%ERL	ISPD
600.	80.0	1.50	13.4	40.0	5.00	12.00	17.36	31.36	75.5	1.157	9.9	408.7	5.1	1.2	1.7	.8	1.7	365.9
600.	80.0	1.50	13.4	60.0	5.00	12.00	22.56	36.56	78.0	1.149	10.0	414.3	5.5	1.0	1.8	.7	1.7	369.8
600.	80.0	1.50	13.4	80.0	5.00	12.00	27.41	41.41	80.8	1.144	10.1	417.7	5.7	.8	1.9	.7	1.7	372.3
600.	80.0	1.60	13.4	40.0	5.00	12.00	17.33	31.33	75.5	1.155	10.3	411.6	5.2	1.1	1.7	1.1	1.9	366.0
600.	80.0	1.60	13.4	60.0	5.00	12.00	22.52	36.52	78.0	1.147	10.5	417.3	5.5	1.0	1.8	1.1	1.9	370.0
600.	80.0	1.60	13.4	80.0	5.00	12.00	27.36	41.36	80.8	1.142	10.6	420.9	5.7	.8	1.9	1.0	1.9	372.5
600.	80.0	1.70	13.4	40.0	5.00	12.00	17.31	31.31	75.5	1.153	10.8	414.1	5.3	1.1	1.7	1.6	2.1	365.3
600.	80.0	1.70	13.4	60.0	5.00	12.00	22.49	36.49	78.0	1.145	10.9	420.0	5.6	1.0	1.8	1.6	2.1	369.2
600.	80.0	1.70	13.4	80.0	5.00	12.00	27.31	41.31	80.8	1.140	11.0	423.7	5.9	.8	1.9	1.6	2.1	371.7
600.	80.0	1.80	13.4	40.0	5.00	12.00	17.28	31.28	75.5	1.151	11.2	416.3	5.5	1.1	1.7	2.1	2.1	364.0
600.	80.0	1.80	13.4	60.0	5.00	12.00	22.44	36.44	78.0	1.143	11.4	422.4	5.9	1.0	1.8	2.1	2.1	367.9
600.	80.0	1.80	13.4	80.0	5.00	12.00	27.26	41.26	80.8	1.138	11.5	426.2	6.1	.8	1.9	2.1	2.1	370.3
600.	80.0	1.40	17.2	40.0	1.50	15.00	17.39	34.39	75.5	1.159	13.9	405.4	5.0	1.2	1.7	1.0	.9	366.0
600.	80.0	1.40	17.2	60.0	1.50	15.00	22.61	39.61	78.0	1.151	14.1	410.8	5.3	1.0	1.8	.9	.9	370.0
600.	80.0	1.40	17.2	80.0	1.50	15.00	27.47	44.47	80.8	1.147	14.2	414.1	5.5	.9	2.0	.9	.9	372.5
600.	80.0	1.50	17.2	40.0	1.50	15.00	17.36	34.36	75.5	1.157	14.0	408.7	5.1	1.2	1.7	1.2	1.0	367.4
600.	80.0	1.50	17.2	60.0	1.50	15.00	22.56	39.56	78.0	1.149	14.2	414.3	5.5	1.0	1.8	1.1	1.0	371.4
600.	80.0	1.50	17.2	80.0	1.50	15.00	27.41	44.41	80.8	1.144	14.3	417.7	5.7	.9	1.9	1.1	1.0	373.9
600.	80.0	1.60	17.2	40.0	1.50	15.00	17.33	34.33	75.5	1.155	14.0	411.6	5.2	1.2	1.7	1.7	1.0	367.5
600.	80.0	1.60	17.2	60.0	1.50	15.00	22.52	39.52	78.0	1.147	14.2	417.3	5.5	1.0	1.8	1.7	1.0	371.5
600.	80.0	1.60	17.2	80.0	1.50	15.00	27.36	44.36	80.8	1.142	14.4	420.9	5.7	.8	1.9	1.6	1.0	374.0
600.	80.0	1.70	17.2	40.0	1.50	15.00	17.31	34.31	75.5	1.153	14.1	414.1	5.3	1.1	1.7	2.3	1.0	366.8
600.	80.0	1.70	17.2	60.0	1.50	15.00	22.49	39.49	78.0	1.145	14.3	420.0	5.6	1.0	1.8	2.3	1.0	370.7
600.	80.0	1.70	17.2	80.0	1.50	15.00	27.31	44.31	80.8	1.140	14.4	423.7	5.9	.8	1.9	2.3	1.0	373.2
600.	80.0	1.80	17.2	40.0	1.50	15.00	17.28	34.28	75.5	1.151	14.1	416.3	5.5	1.1	1.7	2.9	.9	365.6
600.	80.0	1.80	17.2	60.0	1.50	15.00	22.44	39.44	78.0	1.143	14.3	422.4	5.9	1.0	1.8	2.9	.9	369.5
600.	80.0	1.80	17.2	80.0	1.50	15.00	27.26	44.26	80.8	1.138	14.5	426.2	6.1	.8	1.9	2.9	.9	371.9
600.	80.0	1.40	17.2	40.0	2.25	15.00	17.39	34.39	75.5	1.159	9.8	405.4	5.0	1.2	1.7	1.0	.7	367.0
600.	80.0	1.40	17.2	60.0	2.25	15.00	22.61	39.61	78.0	1.151	9.9	410.8	5.3	1.0	1.8	.9	.7	370.9
600.	80.0	1.40	17.2	80.0	2.25	15.00	27.47	44.47	80.8	1.147	10.0	414.1	5.5	.9	2.0	.9	.7	373.4
600.	80.0	1.50	17.2	40.0	2.25	15.00	17.36	34.36	75.5	1.157	10.3	408.7	5.1	1.2	1.7	1.2	.8	368.2
600.	80.0	1.50	17.2	60.0	2.25	15.00	22.56	39.56	78.0	1.149	10.4	414.3	5.5	1.0	1.8	1.1	.8	372.2
600.	80.0	1.50	17.2	80.0	2.25	15.00	27.41	44.41	80.8	1.144	10.5	417.7	5.7	.9	1.9	1.1	.8	374.7
600.	80.0	1.60	17.2	40.0	2.25	15.00	17.33	34.33	75.5	1.155	10.8	411.6	5.2	1.2	1.7	1.7	.8	368.1
600.	80.0	1.60	17.2	60.0	2.25	15.00	22.52	39.52	78.0	1.147	10.9	417.3	5.5	1.0	1.8	1.7	.8	372.1
600.	80.0	1.60	17.2	80.0	2.25	15.00	27.36	44.36	80.8	1.142	11.0	420.9	5.7	.8	1.9	1.6	.8	374.6
600.	80.0	1.70	17.2	40.0	2.25	15.00	17.31	34.31	75.5	1.153	11.3	414.1	5.3	1.1	1.7	2.3	.9	367.1
600.	80.0	1.70	17.2	60.0	2.25	15.00	22.49	39.49	78.0	1.145	11.4	420.0	5.6	1.0	1.8	2.3	.9	371.1
600.	80.0	1.70	17.2	80.0	2.25	15.00	27.31	44.31	80.8	1.140	11.5	423.7	5.9	.8	1.9	2.3	.9	373.5
600.	80.0	1.80	17.2	40.0	2.25	15.00	17.28	34.28	75.5	1.151	11.8	416.3	5.5	1.1	1.7	2.9	.9	365.7

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD
600.	80.0	1.80	17.2	60.0	2.25	15.00	22.44	39.44	78.0	1.143	11.9	422.4	5.9	1.0	1.8	2.9	.9	369.6
600.	80.0	1.80	17.2	80.0	2.25	15.00	27.26	44.26	80.8	1.138	12.0	426.2	6.1	.8	1.9	2.9	.9	372.0
600.	80.0	1.40	17.2	40.0	5.00	15.00	17.39	34.39	75.5	1.159	9.8	405.4	5.0	1.2	1.7	1.0	1.1	365.1
600.	80.0	1.40	17.2	60.0	5.00	15.00	22.61	39.61	78.0	1.151	9.9	410.8	5.3	1.0	1.8	.9	1.1	369.1
600.	80.0	1.40	17.2	80.0	5.00	15.00	27.47	44.47	80.8	1.147	10.0	414.1	5.5	.9	2.0	.9	1.1	371.5
600.	80.0	1.50	17.2	40.0	5.00	15.00	17.36	34.36	75.5	1.157	10.3	408.7	5.1	1.2	1.7	1.2	1.3	366.1
600.	80.0	1.50	17.2	60.0	5.00	15.00	22.56	39.56	78.0	1.149	10.4	414.3	5.5	1.0	1.8	1.1	1.3	370.0
600.	80.0	1.50	17.2	80.0	5.00	15.00	27.41	44.41	80.8	1.144	10.5	417.7	5.7	.8	1.9	1.1	1.3	372.5
600.	80.0	1.60	17.2	40.0	5.00	15.00	17.33	34.33	75.5	1.155	10.8	411.6	5.2	1.1	1.7	1.7	1.4	365.8
600.	80.0	1.60	17.2	60.0	5.00	15.00	22.52	39.52	78.0	1.147	10.9	417.3	5.5	1.0	1.8	1.7	1.4	369.7
600.	80.0	1.60	17.2	80.0	5.00	15.00	27.36	44.36	80.8	1.142	11.0	420.9	5.7	.8	1.9	1.6	1.4	372.2
600.	80.0	1.70	17.2	40.0	5.00	15.00	17.31	34.31	75.5	1.153	11.3	414.1	5.3	1.1	1.7	2.3	1.5	364.7
600.	80.0	1.70	17.2	60.0	5.00	15.00	22.49	39.49	78.0	1.145	11.4	420.0	5.6	1.0	1.8	2.3	1.5	368.6
600.	80.0	1.70	17.2	80.0	5.00	15.00	27.31	44.31	80.8	1.140	11.5	423.7	5.9	.8	1.9	2.3	1.5	371.0
600.	80.0	1.80	17.2	40.0	5.00	15.00	17.28	34.28	75.5	1.151	11.8	416.3	5.5	1.1	1.7	2.9	1.5	363.3
600.	80.0	1.80	17.2	60.0	5.00	15.00	22.44	39.44	78.0	1.143	11.9	422.4	5.9	1.0	1.8	2.9	1.5	367.1
600.	80.0	1.80	17.2	80.0	5.00	15.00	27.26	44.26	80.8	1.138	12.0	426.2	6.1	.8	1.9	2.9	1.5	369.5
600.	120.0	1.40	5.0	40.0	1.50	6.00	14.23	22.23	75.5	.948	20.8	406.0	4.1	1.1	1.6	.3	4.6	358.6
600.	120.0	1.40	5.0	60.0	1.50	6.00	18.49	26.49	78.0	.942	21.1	411.3	4.3	1.0	1.8	.3	4.5	362.6
600.	120.0	1.40	5.0	80.0	1.50	6.00	22.47	30.47	80.8	.938	21.3	414.5	4.4	.8	1.9	.3	4.5	365.1
600.	120.0	1.50	5.0	40.0	1.50	6.00	14.20	22.20	75.5	.946	20.9	409.4	4.2	1.1	1.6	.3	4.5	361.5
600.	120.0	1.50	5.0	60.0	1.50	6.00	18.45	26.45	78.0	.940	21.2	414.9	4.4	1.0	1.8	.2	4.5	365.5
600.	120.0	1.50	5.0	80.0	1.50	6.00	22.42	30.42	80.8	.936	21.4	418.2	4.6	.8	1.9	.2	4.4	368.1
600.	120.0	1.60	5.0	40.0	1.50	6.00	14.18	22.18	75.5	.945	21.0	412.3	4.3	1.1	1.6	.3	4.5	363.4
600.	120.0	1.60	5.0	60.0	1.50	6.00	18.42	26.42	78.0	.938	21.3	417.9	4.5	1.0	1.8	.3	4.5	367.5
600.	120.0	1.60	5.0	80.0	1.50	6.00	22.38	30.38	80.8	.934	21.5	421.4	4.7	.8	1.9	.3	4.5	370.0
600.	120.0	1.70	5.0	40.0	1.50	6.00	14.16	22.16	75.5	.943	21.0	414.8	4.4	1.1	1.6	.4	4.6	364.4
600.	120.0	1.70	5.0	60.0	1.50	6.00	18.39	26.39	78.0	.937	21.3	420.6	4.7	1.0	1.8	.4	4.6	368.6
600.	120.0	1.70	5.0	80.0	1.50	6.00	22.34	30.34	80.8	.933	21.5	424.3	4.9	.8	1.9	.4	4.6	371.1
600.	120.0	1.80	5.0	40.0	1.50	6.00	14.13	22.13	75.5	.942	21.1	417.1	4.6	1.1	1.6	.5	4.7	364.7
600.	120.0	1.80	5.0	60.0	1.50	6.00	18.36	26.36	78.0	.935	21.4	423.1	4.9	1.0	1.8	.5	4.7	368.8
600.	120.0	1.80	5.0	80.0	1.50	6.00	22.30	30.30	80.8	.931	21.6	426.9	5.1	.8	1.9	.5	4.7	371.3
600.	120.0	1.40	5.0	40.0	2.25	6.00	14.23	22.23	75.5	.948	13.9	406.0	4.1	1.2	1.6	.3	3.4	363.5
600.	120.0	1.40	5.0	60.0	2.25	6.00	18.49	26.49	78.0	.942	14.1	411.3	4.3	1.0	1.8	.3	3.3	367.5
600.	120.0	1.40	5.0	80.0	2.25	6.00	22.47	30.47	80.8	.938	14.2	414.5	4.4	.8	1.9	.3	3.3	370.0
600.	120.0	1.50	5.0	40.0	2.25	6.00	14.20	22.20	75.5	.946	13.9	409.4	4.2	1.2	1.6	.3	3.2	366.5
600.	120.0	1.50	5.0	60.0	2.25	6.00	18.45	26.45	78.0	.940	14.1	414.9	4.4	1.0	1.8	.2	3.2	370.7
600.	120.0	1.50	5.0	80.0	2.25	6.00	22.42	30.42	80.8	.936	14.2	418.2	4.6	.8	1.9	.2	3.2	373.2
600.	120.0	1.60	5.0	40.0	2.25	6.00	14.18	22.18	75.5	.945	14.0	412.3	4.3	1.2	1.6	.3	3.3	368.6
600.	120.0	1.60	5.0	60.0	2.25	6.00	18.42	26.42	78.0	.938	14.2	417.9	4.5	1.0	1.8	.3	3.2	372.8

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%ERL	ISPC
600.	120.0	1.60	5.0	80.0	2.25	6.00	22.38	30.38	80.8	.934	14.3	421.4	4.7	.8	1.9	.3	3.2	375.4
600.	120.0	1.70	5.0	40.0	2.25	6.00	14.16	22.16	75.5	.943	14.0	414.8	4.4	1.2	1.6	.4	3.3	369.9
600.	120.0	1.70	5.0	60.0	2.25	6.00	18.39	26.39	78.0	.937	14.2	420.6	4.7	1.0	1.8	.4	3.3	374.1
600.	120.0	1.70	5.0	80.0	2.25	6.00	22.34	30.34	80.8	.933	14.4	424.3	4.9	.8	1.9	.4	3.3	376.6
600.	120.0	1.80	5.0	40.0	2.25	6.00	14.13	22.13	75.5	.942	14.1	417.1	4.6	1.1	1.6	.5	3.3	370.4
600.	120.0	1.80	5.0	60.0	2.25	6.00	18.36	26.36	78.0	.935	14.3	423.1	4.9	1.0	1.8	.5	3.3	374.6
600.	120.0	1.80	5.0	80.0	2.25	6.00	22.30	30.30	80.8	.931	14.4	426.9	5.1	.8	1.9	.5	3.3	377.1
600.	120.0	1.40	5.0	40.0	5.00	6.00	14.23	22.23	75.5	.948	10.5	406.0	4.1	1.2	1.6	.3	2.9	365.2
600.	120.0	1.40	5.0	60.0	5.00	6.00	18.49	26.49	78.0	.942	10.6	411.3	4.3	1.0	1.8	.3	2.9	369.3
600.	120.0	1.40	5.0	80.0	5.00	6.00	22.47	30.47	80.8	.938	10.7	414.5	4.4	.9	1.9	.3	2.9	371.8
600.	120.0	1.50	5.0	40.0	5.00	6.00	14.20	22.20	75.5	.946	11.0	409.4	4.2	1.2	1.6	.3	2.9	367.8
600.	120.0	1.50	5.0	60.0	5.00	6.00	18.45	26.45	78.0	.940	11.2	414.9	4.4	1.0	1.8	.2	2.9	371.9
600.	120.0	1.50	5.0	80.0	5.00	6.00	22.42	30.42	80.8	.936	11.3	418.2	4.6	.9	1.9	.2	2.9	374.5
600.	120.0	1.60	5.0	40.0	5.00	6.00	14.18	22.18	75.5	.945	11.5	412.3	4.3	1.2	1.6	.3	3.1	369.4
600.	120.0	1.60	5.0	60.0	5.00	6.00	18.42	26.42	78.0	.938	11.7	417.9	4.5	1.0	1.8	.3	3.0	373.6
600.	120.0	1.60	5.0	80.0	5.00	6.00	22.38	30.38	80.8	.934	11.8	421.4	4.7	.8	1.9	.3	3.0	376.2
600.	120.0	1.70	5.0	40.0	5.00	6.00	14.16	22.16	75.5	.943	12.1	414.8	4.4	1.2	1.6	.4	3.2	370.1
600.	120.0	1.70	5.0	60.0	5.00	6.00	18.39	26.39	78.0	.937	12.2	420.6	4.7	1.0	1.8	.4	3.2	374.3
600.	120.0	1.70	5.0	80.0	5.00	6.00	22.34	30.34	80.8	.933	12.3	424.3	4.9	.8	1.9	.4	3.2	376.9
600.	120.0	1.80	5.0	40.0	5.00	6.00	14.13	22.13	75.5	.942	12.6	417.1	4.6	1.1	1.6	.5	3.4	370.1
600.	120.0	1.80	5.0	60.0	5.00	6.00	18.36	26.36	78.0	.935	12.8	423.1	4.9	1.0	1.8	.5	3.4	374.3
600.	120.0	1.80	5.0	80.0	5.00	6.00	22.30	30.30	80.8	.931	12.9	426.9	5.1	.8	1.9	.5	3.4	376.8
600.	120.0	1.40	13.4	40.0	1.50	12.00	14.23	28.23	75.5	.948	20.8	406.0	4.1	1.2	1.6	.7	1.4	369.6
600.	120.0	1.40	13.4	60.0	1.50	12.00	18.49	32.49	78.0	.942	21.1	411.3	4.3	1.0	1.8	.7	1.4	373.7
600.	120.0	1.40	13.4	80.0	1.50	12.00	22.47	36.47	80.8	.938	21.3	414.5	4.4	.9	1.9	.7	1.4	376.3
600.	120.0	1.50	13.4	40.0	1.50	12.00	14.20	28.20	75.5	.946	20.9	409.4	4.2	1.2	1.6	.8	1.4	371.9
600.	120.0	1.50	13.4	60.0	1.50	12.00	18.45	32.45	78.0	.940	21.2	414.9	4.4	1.0	1.8	.8	1.4	376.1
600.	120.0	1.50	13.4	80.0	1.50	12.00	22.42	36.42	80.8	.936	21.4	418.2	4.6	.9	1.9	.7	1.4	378.7
600.	120.0	1.60	13.4	40.0	1.50	12.00	14.18	28.18	75.5	.945	21.0	412.3	4.3	1.2	1.6	1.0	1.4	373.2
600.	120.0	1.60	13.4	60.0	1.50	12.00	18.42	32.42	78.0	.938	21.3	417.9	4.5	1.0	1.8	1.0	1.4	377.5
600.	120.0	1.60	13.4	80.0	1.50	12.00	22.38	36.38	80.8	.934	21.5	421.4	4.7	.9	1.9	1.0	1.4	380.1
600.	120.0	1.70	13.4	40.0	1.50	12.00	14.16	28.16	75.5	.943	21.0	414.8	4.4	1.2	1.6	1.4	1.4	373.7
600.	120.0	1.70	13.4	60.0	1.50	12.00	18.39	32.39	78.0	.937	21.3	420.6	4.7	1.0	1.8	1.4	1.4	378.0
600.	120.0	1.70	13.4	80.0	1.50	12.00	22.34	36.34	80.8	.933	21.5	424.3	4.9	.9	1.9	1.3	1.4	380.6
600.	120.0	1.80	13.4	40.0	1.50	12.00	14.13	28.13	75.5	.942	21.1	417.1	4.6	1.2	1.6	1.7	1.4	373.5
600.	120.0	1.80	13.4	60.0	1.50	12.00	18.36	32.36	78.0	.935	21.4	423.1	4.9	1.0	1.8	1.7	1.4	377.7
600.	120.0	1.80	13.4	80.0	1.50	12.00	22.30	36.30	80.8	.931	21.6	426.9	5.1	.8	1.9	1.7	1.4	380.3
600.	120.0	1.40	13.4	40.0	2.25	12.00	14.23	28.23	75.5	.948	13.9	406.0	4.1	1.2	1.6	.7	1.0	371.2
600.	120.0	1.40	13.4	60.0	2.25	12.00	18.49	32.49	78.0	.942	14.1	411.3	4.3	1.0	1.8	.7	1.0	375.4
600.	120.0	1.40	13.4	80.0	2.25	12.00	22.47	36.47	80.8	.938	14.2	414.5	4.4	.9	1.9	.7	1.0	377.9

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD
600.	120.0	1.50	13.4	40.0	2.25	12.00	14.20	28.20	75.5	.946	13.9	409.4	4.2	1.2	1.6	.8	1.0	373.6
600.	120.0	1.50	13.4	60.0	2.25	12.00	18.45	32.45	78.0	.940	14.1	414.9	4.4	1.0	1.8	.8	1.0	377.8
600.	120.0	1.50	13.4	80.0	2.25	12.00	22.42	36.42	80.8	.936	14.2	418.2	4.6	.9	1.9	.7	1.0	380.4
600.	120.0	1.60	13.4	40.0	2.25	12.00	14.18	28.18	75.5	.945	14.0	412.3	4.3	1.2	1.6	1.0	1.0	374.9
600.	120.0	1.60	13.4	60.0	2.25	12.00	18.42	32.42	78.0	.938	14.2	417.9	4.5	1.0	1.8	1.0	1.0	379.2
600.	120.0	1.60	13.4	80.0	2.25	12.00	22.38	36.38	80.8	.934	14.3	421.4	4.7	.9	1.9	1.0	1.0	381.8
600.	120.0	1.70	13.4	40.0	2.25	12.00	14.16	28.16	75.5	.943	14.0	414.8	4.4	1.2	1.6	1.4	1.0	375.5
600.	120.0	1.70	13.4	60.0	2.25	12.00	18.39	32.39	78.0	.937	14.2	420.6	4.7	1.0	1.8	1.4	1.0	379.8
600.	120.0	1.70	13.4	80.0	2.25	12.00	22.34	36.34	80.8	.933	14.4	424.3	4.9	.9	1.9	1.3	1.0	382.4
600.	120.0	1.80	13.4	40.0	2.25	12.00	14.13	28.13	75.5	.942	14.1	417.1	4.6	1.2	1.6	1.7	1.0	375.3
600.	120.0	1.80	13.4	60.0	2.25	12.00	18.36	32.36	78.0	.935	14.3	423.1	4.9	1.0	1.8	1.7	1.0	379.5
600.	120.0	1.80	13.4	80.0	2.25	12.00	22.30	36.30	80.8	.931	14.4	426.9	5.1	.9	1.9	1.7	1.0	382.1
600.	120.0	1.40	13.4	40.0	5.00	12.00	14.23	28.23	75.5	.948	11.5	406.0	4.1	1.2	1.6	.7	1.1	370.5
600.	120.0	1.40	13.4	60.0	5.00	12.00	18.49	32.49	78.0	.942	11.7	411.3	4.3	1.0	1.8	.7	1.1	374.7
600.	120.0	1.40	13.4	80.0	5.00	12.00	22.47	36.47	80.8	.938	11.7	414.5	4.4	.9	1.9	.7	1.1	377.3
600.	120.0	1.50	13.4	40.0	5.00	12.00	14.20	28.20	75.5	.946	12.1	409.4	4.2	1.2	1.6	.8	1.2	372.6
600.	120.0	1.50	13.4	60.0	5.00	12.00	18.45	32.45	78.0	.940	12.2	414.9	4.4	1.0	1.8	.8	1.2	376.8
600.	120.0	1.50	13.4	80.0	5.00	12.00	22.42	36.42	80.8	.936	12.3	418.2	4.6	.9	1.9	.7	1.2	379.4
600.	120.0	1.60	13.4	40.0	5.00	12.00	14.18	28.18	75.5	.945	12.7	412.3	4.3	1.2	1.6	1.0	1.3	373.6
600.	120.0	1.60	13.4	60.0	5.00	12.00	18.42	32.42	78.0	.938	12.8	417.9	4.5	1.0	1.8	1.0	1.3	377.9
600.	120.0	1.60	13.4	80.0	5.00	12.00	22.38	36.38	80.8	.934	12.9	421.4	4.7	.9	1.9	1.0	1.3	380.5
600.	120.0	1.70	13.4	40.0	5.00	12.00	14.16	28.16	75.5	.943	13.2	414.8	4.4	1.2	1.6	1.4	1.4	373.9
600.	120.0	1.70	13.4	60.0	5.00	12.00	18.39	32.39	78.0	.937	13.4	420.6	4.7	1.0	1.8	1.4	1.3	378.1
600.	120.0	1.70	13.4	80.0	5.00	12.00	22.34	36.34	80.8	.933	13.5	424.3	4.9	.9	1.9	1.3	1.4	380.7
600.	120.0	1.80	13.4	40.0	5.00	12.00	14.13	28.13	75.5	.942	13.8	417.1	4.6	1.2	1.6	1.7	1.4	373.3
600.	120.0	1.80	13.4	60.0	5.00	12.00	18.36	32.36	78.0	.935	14.0	423.1	4.9	1.0	1.8	1.7	1.4	377.5
600.	120.0	1.80	13.4	80.0	5.00	12.00	22.30	36.30	80.8	.931	14.1	426.9	5.1	.8	1.9	1.7	1.4	380.1
600.	120.0	1.40	17.2	40.0	1.50	15.00	14.23	31.23	75.5	.948	20.8	406.0	4.1	1.2	1.6	1.0	.8	370.8
600.	120.0	1.40	17.2	60.0	1.50	15.00	18.49	35.49	78.0	.942	21.1	411.3	4.3	1.0	1.8	.9	.8	375.0
600.	120.0	1.40	17.2	80.0	1.50	15.00	22.47	39.47	80.8	.938	21.3	414.5	4.4	.9	1.9	.9	.8	377.6
600.	120.0	1.50	17.2	40.0	1.50	15.00	14.20	31.20	75.5	.946	20.9	409.4	4.2	1.2	1.6	1.1	.8	372.6
600.	120.0	1.50	17.2	60.0	1.50	15.00	18.45	35.45	78.0	.940	21.2	414.9	4.4	1.0	1.8	1.1	.8	376.9
600.	120.0	1.50	17.2	80.0	1.50	15.00	22.42	39.42	80.8	.936	21.4	418.2	4.6	.9	1.9	1.1	.8	379.5
600.	120.0	1.60	17.2	40.0	1.50	15.00	14.18	31.18	75.5	.945	21.0	412.3	4.3	1.2	1.6	1.5	.8	373.5
600.	120.0	1.60	17.2	60.0	1.50	15.00	18.42	35.42	78.0	.938	21.3	417.9	4.5	1.0	1.8	1.5	.8	377.8
600.	120.0	1.60	17.2	80.0	1.50	15.00	22.38	39.38	80.8	.934	21.5	421.4	4.7	.9	1.9	1.5	.8	380.4
600.	120.0	1.70	17.2	40.0	1.50	15.00	14.16	31.16	75.5	.943	21.0	414.8	4.4	1.2	1.6	2.0	.8	373.6
600.	120.0	1.70	17.2	60.0	1.50	15.00	18.39	35.39	78.0	.937	21.3	420.6	4.7	1.0	1.8	2.0	.8	377.9
600.	120.0	1.70	17.2	80.0	1.50	15.00	22.34	39.34	80.8	.933	21.5	424.3	4.9	.9	1.9	2.0	.8	380.4
600.	120.0	1.80	17.2	40.0	1.50	15.00	14.13	31.13	75.5	.942	21.1	417.1	4.6	1.2	1.6	2.5	.8	373.0

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%ERL	ISPD
600.	120.0	1.80	17.2	60.0	1.50	15.00	18.36	35.36	78.0	.935	21.4	423.1	4.9	1.0	1.8	2.4	.8	377.2
600.	120.0	1.80	17.2	80.0	1.50	15.00	22.30	39.30	80.8	.931	21.6	426.9	5.1	.8	1.9	2.5	.8	379.7
600.	120.0	1.40	17.2	40.0	2.25	15.00	14.23	31.23	75.5	.948	13.9	406.0	4.1	1.2	1.6	1.0	.5	371.9
600.	120.0	1.40	17.2	60.0	2.25	15.00	18.49	35.49	78.0	.942	14.1	411.3	4.3	1.0	1.8	.9	.5	376.1
600.	120.0	1.40	17.2	80.0	2.25	15.00	22.47	39.47	80.8	.938	14.2	414.5	4.4	.9	1.9	.9	.5	378.7
600.	120.0	1.50	17.2	40.0	2.25	15.00	14.20	31.20	75.5	.946	13.9	409.4	4.2	1.2	1.6	1.1	.5	373.8
600.	120.0	1.50	17.2	60.0	2.25	15.00	18.45	35.45	78.0	.940	14.1	414.9	4.4	1.0	1.8	1.1	.5	378.1
600.	120.0	1.50	17.2	80.0	2.25	15.00	22.42	39.42	80.8	.936	14.2	418.2	4.6	.9	1.9	1.1	.5	380.7
600.	120.0	1.60	17.2	40.0	2.25	15.00	14.18	31.18	75.5	.945	14.0	412.3	4.3	1.2	1.6	1.5	.5	374.8
600.	120.0	1.60	17.2	60.0	2.25	15.00	18.42	35.42	78.0	.938	14.2	417.9	4.5	1.0	1.8	1.5	.5	379.0
600.	120.0	1.60	17.2	80.0	2.25	15.00	22.38	39.38	80.8	.934	14.3	421.4	4.7	.9	1.9	1.5	.5	381.6
600.	120.0	1.70	17.2	40.0	2.25	15.00	14.16	31.16	75.5	.943	14.0	414.8	4.4	1.2	1.6	2.0	.5	374.8
600.	120.0	1.70	17.2	60.0	2.25	15.00	18.39	35.39	78.0	.937	14.2	420.6	4.7	1.0	1.8	2.0	.5	379.1
600.	120.0	1.70	17.2	80.0	2.25	15.00	22.34	39.34	80.8	.933	14.4	424.3	4.9	.9	1.9	2.0	.5	381.7
600.	120.0	1.80	17.2	40.0	2.25	15.00	14.13	31.13	75.5	.942	14.4	417.1	4.6	1.2	1.6	2.5	.5	374.1
600.	120.0	1.80	17.2	60.0	2.25	15.00	18.36	35.36	78.0	.935	14.6	423.1	4.9	1.0	1.8	2.4	.5	378.3
600.	120.0	1.80	17.2	80.0	2.25	15.00	22.30	39.30	80.8	.931	14.8	426.9	5.1	.8	1.9	2.5	.5	380.8
600.	120.0	1.40	17.2	40.0	5.00	15.00	14.23	31.23	75.5	.948	12.0	406.0	4.1	1.2	1.6	1.0	.8	371.0
600.	120.0	1.40	17.2	60.0	5.00	15.00	18.49	35.49	78.0	.942	12.2	411.3	4.3	1.0	1.8	.9	.8	375.2
600.	120.0	1.40	17.2	80.0	5.00	15.00	22.47	39.47	80.8	.938	12.3	414.5	4.4	.9	1.9	.9	.8	377.8
600.	120.0	1.50	17.2	40.0	5.00	15.00	14.20	31.20	75.5	.946	12.6	409.4	4.2	1.2	1.6	1.1	.8	372.6
600.	120.0	1.50	17.2	60.0	5.00	15.00	18.45	35.45	78.0	.940	12.8	414.9	4.4	1.0	1.8	1.1	.8	376.8
600.	120.0	1.50	17.2	80.0	5.00	15.00	22.42	39.42	80.8	.936	12.9	418.2	4.6	.9	1.9	1.1	.8	379.4
600.	120.0	1.60	17.2	40.0	5.00	15.00	14.18	31.18	75.5	.945	13.2	412.3	4.3	1.2	1.6	1.5	.9	373.3
600.	120.0	1.60	17.2	60.0	5.00	15.00	18.42	35.42	78.0	.938	13.4	417.9	4.5	1.0	1.8	1.5	.9	377.5
600.	120.0	1.60	17.2	80.0	5.00	15.00	22.38	39.38	80.8	.934	13.5	421.4	4.7	.9	1.9	1.5	.9	380.1
600.	120.0	1.70	17.2	40.0	5.00	15.00	14.16	31.16	75.5	.943	13.8	414.8	4.4	1.2	1.6	2.0	.9	373.1
600.	120.0	1.70	17.2	60.0	5.00	15.00	18.39	35.39	78.0	.937	14.0	420.6	4.7	1.0	1.8	2.0	.9	377.3
600.	120.0	1.70	17.2	80.0	5.00	15.00	22.34	39.34	80.8	.933	14.2	424.3	4.9	.9	1.9	2.0	.9	379.9
600.	120.0	1.80	17.2	40.0	5.00	15.00	14.13	31.13	75.5	.942	14.4	417.1	4.6	1.2	1.6	2.5	1.0	372.1
600.	120.0	1.80	17.2	60.0	5.00	15.00	18.36	35.36	78.0	.935	14.6	423.1	4.9	1.0	1.8	2.4	1.0	376.3
600.	120.0	1.80	17.2	80.0	5.00	15.00	22.30	39.30	80.8	.931	14.8	426.9	5.1	.8	1.9	2.5	1.0	378.8
600.	200.0	1.40	5.0	40.0	1.50	6.00	11.04	19.04	75.5	.736	34.6	406.7	3.2	1.2	1.6	.3	4.4	364.0
600.	200.0	1.40	5.0	60.0	1.50	6.00	14.36	22.36	78.0	.731	35.0	411.8	3.3	1.0	1.7	.2	4.3	368.3
600.	200.0	1.40	5.0	80.0	1.50	6.00	17.45	25.45	80.8	.728	35.3	415.0	3.4	.9	1.8	.2	4.3	370.9
600.	200.0	1.50	5.0	40.0	1.50	6.00	11.02	19.02	75.5	.734	34.7	410.2	3.3	1.2	1.6	.3	4.2	367.3
600.	200.0	1.50	5.0	60.0	1.50	6.00	14.33	22.33	78.0	.730	35.2	415.5	3.5	1.0	1.7	.3	4.1	371.7
600.	200.0	1.50	5.0	80.0	1.50	6.00	17.41	25.41	80.8	.727	35.4	418.8	3.6	.9	1.8	.3	4.1	374.4
600.	200.0	1.60	5.0	40.0	1.50	6.00	11.01	19.01	75.5	.733	34.8	413.1	3.4	1.2	1.6	.3	4.1	370.0
600.	200.0	1.60	5.0	60.0	1.50	6.00	14.30	22.30	78.0	.728	35.3	418.6	3.6	1.0	1.7	.3	4.0	374.5

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD
600.	200.0	1.60	5.0	80.0	1.50	6.00	17.38	25.38	80.8	.725	35.6	422.0	3.7	.9	1.8	.3	4.0	377.2
600.	200.0	1.70	5.0	40.0	1.50	6.00	10.99	18.99	75.5	.732	34.9	415.7	3.5	1.2	1.5	.4	4.0	372.0
600.	200.0	1.70	5.0	60.0	1.50	6.00	14.28	22.28	78.0	.727	35.4	421.4	3.7	1.0	1.7	.3	3.9	376.6
600.	200.0	1.70	5.0	80.0	1.50	6.00	17.35	25.35	80.8	.724	35.7	424.9	3.8	.8	1.8	.3	3.9	379.3
600.	200.0	1.80	5.0	40.0	1.50	6.00	10.97	18.97	75.5	.731	35.0	418.1	3.6	1.2	1.5	.4	4.0	373.0
600.	200.0	1.80	5.0	60.0	1.50	6.00	14.25	22.25	78.0	.726	35.5	424.0	3.9	1.0	1.7	.4	4.0	377.6
600.	200.0	1.80	5.0	80.0	1.50	6.00	17.32	25.32	80.8	.723	35.8	427.6	4.0	.8	1.8	.4	4.0	380.4
600.	200.0	1.40	5.0	40.0	2.25	6.00	11.04	19.04	75.5	.736	23.1	406.7	3.2	1.2	1.6	.3	3.2	368.7
600.	200.0	1.40	5.0	60.0	2.25	6.00	14.36	22.36	78.0	.731	23.3	411.8	3.3	1.0	1.7	.2	3.2	373.1
600.	200.0	1.40	5.0	80.0	2.25	6.00	17.45	25.45	80.8	.728	23.5	415.0	3.4	.9	1.8	.2	3.2	375.7
600.	200.0	1.50	5.0	40.0	2.25	6.00	11.02	19.02	75.5	.734	23.1	410.2	3.3	1.2	1.6	.3	3.0	372.0
600.	200.0	1.50	5.0	60.0	2.25	6.00	14.33	22.33	78.0	.730	23.4	415.5	3.5	1.0	1.7	.3	3.0	376.4
600.	200.0	1.50	5.0	80.0	2.25	6.00	17.41	25.41	80.8	.727	23.6	418.8	3.6	.9	1.8	.3	3.0	379.1
600.	200.0	1.60	5.0	40.0	2.25	6.00	11.01	19.01	75.5	.733	23.2	413.1	3.4	1.2	1.6	.3	2.9	374.7
600.	200.0	1.60	5.0	60.0	2.25	6.00	14.30	22.30	78.0	.728	23.5	418.6	3.6	1.0	1.7	.3	2.9	379.2
600.	200.0	1.60	5.0	80.0	2.25	6.00	17.38	25.38	80.8	.725	23.7	422.0	3.7	.9	1.8	.3	2.9	381.9
600.	200.0	1.70	5.0	40.0	2.25	6.00	10.99	18.99	75.5	.732	23.3	415.7	3.5	1.2	1.5	.4	2.8	376.8
600.	200.0	1.70	5.0	60.0	2.25	6.00	14.28	22.28	78.0	.727	23.6	421.4	3.7	1.0	1.7	.3	2.8	381.4
600.	200.0	1.70	5.0	80.0	2.25	6.00	17.35	25.35	80.8	.724	23.8	424.9	3.8	.9	1.8	.3	2.8	384.2
600.	200.0	1.80	5.0	40.0	2.25	6.00	10.97	18.97	75.5	.731	23.4	418.1	3.6	1.2	1.5	.4	2.8	378.2
600.	200.0	1.80	5.0	60.0	2.25	6.00	14.25	22.25	78.0	.726	23.7	424.0	3.9	1.0	1.7	.4	2.7	382.9
600.	200.0	1.80	5.0	80.0	2.25	6.00	17.32	25.32	80.8	.723	23.9	427.6	4.0	.9	1.8	.4	2.7	385.7
600.	200.0	1.40	5.0	40.0	5.00	6.00	11.04	19.04	75.5	.736	13.6	406.7	3.2	1.2	1.6	.3	2.1	373.2
600.	200.0	1.40	5.0	60.0	5.00	6.00	14.36	22.36	78.0	.731	13.7	411.8	3.3	1.0	1.7	.2	2.1	377.5
600.	200.0	1.40	5.0	80.0	5.00	6.00	17.45	25.45	80.8	.728	13.8	415.0	3.4	.9	1.8	.2	2.1	380.2
600.	200.0	1.50	5.0	40.0	5.00	6.00	11.02	19.02	75.5	.734	14.3	410.2	3.3	1.2	1.6	.3	2.0	376.0
600.	200.0	1.50	5.0	60.0	5.00	6.00	14.33	22.33	78.0	.730	14.4	415.5	3.5	1.0	1.7	.3	2.0	380.4
600.	200.0	1.50	5.0	80.0	5.00	6.00	17.41	25.41	80.8	.727	14.5	418.8	3.6	.9	1.8	.3	2.0	383.2
600.	200.0	1.60	5.0	40.0	5.00	6.00	11.01	19.01	75.5	.733	14.9	413.1	3.4	1.2	1.6	.3	2.1	378.2
600.	200.0	1.60	5.0	60.0	5.00	6.00	14.30	22.30	78.0	.728	15.1	418.6	3.6	1.0	1.7	.3	2.0	382.7
600.	200.0	1.60	5.0	80.0	5.00	6.00	17.38	25.38	80.8	.725	15.3	422.0	3.7	.9	1.8	.3	2.0	385.4
600.	200.0	1.70	5.0	40.0	5.00	6.00	10.99	18.99	75.5	.732	15.6	415.7	3.5	1.2	1.5	.4	2.1	379.8
600.	200.0	1.70	5.0	60.0	5.00	6.00	14.28	22.28	78.0	.727	15.8	421.4	3.7	1.0	1.7	.3	2.1	384.4
600.	200.0	1.70	5.0	80.0	5.00	6.00	17.35	25.35	80.8	.724	15.9	424.9	3.8	.9	1.8	.3	2.0	387.2
600.	200.0	1.80	5.0	40.0	5.00	6.00	10.97	18.97	75.5	.731	16.3	418.1	3.6	1.2	1.5	.4	2.1	380.9
600.	200.0	1.80	5.0	60.0	5.00	6.00	14.25	22.25	78.0	.726	16.5	424.0	3.9	1.0	1.7	.4	2.1	385.6
600.	200.0	1.80	5.0	80.0	5.00	6.00	17.32	25.32	80.8	.723	16.6	427.6	4.0	.9	1.8	.4	2.1	388.4
600.	200.0	1.40	13.4	40.0	1.50	12.00	11.04	25.04	75.5	.736	34.6	406.7	3.2	1.2	1.6	.7	1.3	374.5
600.	200.0	1.40	13.4	60.0	1.50	12.00	14.36	28.36	78.0	.731	35.0	411.8	3.3	1.0	1.7	.7	1.3	378.9
600.	200.0	1.40	13.4	80.0	1.50	12.00	17.45	31.45	80.8	.728	35.3	415.0	3.4	.9	1.8	.7	1.3	381.6

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD
600.	200.0	1.50	13.4	40.0	1.50	12.00	11.02	25.02	75.5	.734	34.7	410.2	3.3	1.2	1.6	.8	1.2	377.1
600.	200.0	1.50	13.4	60.0	1.50	12.00	14.33	28.33	78.0	.730	35.2	415.5	3.5	1.0	1.7	.8	1.2	381.7
600.	200.0	1.50	13.4	80.0	1.50	12.00	17.41	31.41	80.8	.727	35.4	418.8	3.6	.9	1.8	.8	1.2	384.4
600.	200.0	1.60	13.4	40.0	1.50	12.00	11.01	25.01	75.5	.733	34.8	413.1	3.4	1.2	1.6	.9	1.2	379.2
600.	200.0	1.60	13.4	60.0	1.50	12.00	14.30	28.30	78.0	.728	35.3	418.6	3.6	1.0	1.7	.9	1.1	383.8
600.	200.0	1.60	13.4	80.0	1.50	12.00	17.38	31.38	80.8	.725	35.6	422.0	3.7	.9	1.8	.9	1.1	386.6
600.	200.0	1.70	13.4	40.0	1.50	12.00	10.99	24.99	75.5	.732	34.9	415.7	3.5	1.2	1.5	1.1	1.1	380.6
600.	200.0	1.70	13.4	60.0	1.50	12.00	14.28	28.28	78.0	.727	35.4	421.4	3.7	1.0	1.7	1.1	1.1	385.3
600.	200.0	1.70	13.4	80.0	1.50	12.00	17.35	31.35	80.8	.724	35.7	424.9	3.8	.9	1.8	1.1	1.1	388.1
600.	200.0	1.80	13.4	40.0	1.50	12.00	10.97	24.97	75.5	.731	35.0	418.1	3.6	1.2	1.5	1.3	1.2	381.1
600.	200.0	1.80	13.4	60.0	1.50	12.00	14.25	28.25	78.0	.726	35.5	424.0	3.9	1.0	1.7	1.3	1.2	385.8
600.	200.0	1.80	13.4	80.0	1.50	12.00	17.32	31.32	80.8	.723	35.8	427.6	4.0	.9	1.8	1.3	1.2	388.7
600.	200.0	1.40	13.4	40.0	2.25	12.00	11.04	25.04	75.5	.736	23.1	406.7	3.2	1.2	1.6	.7	.9	376.0
600.	200.0	1.40	13.4	60.0	2.25	12.00	14.36	28.36	78.0	.731	23.3	411.8	3.3	1.0	1.7	.7	.9	380.5
600.	200.0	1.40	13.4	80.0	2.25	12.00	17.45	31.45	80.8	.728	23.5	415.0	3.4	.9	1.8	.7	.9	383.2
600.	200.0	1.50	13.4	40.0	2.25	12.00	11.02	25.02	75.5	.734	23.1	410.2	3.3	1.2	1.6	.8	.8	378.6
600.	200.0	1.50	13.4	60.0	2.25	12.00	14.33	28.33	78.0	.730	23.4	415.5	3.5	1.0	1.7	.8	.8	383.2
600.	200.0	1.50	13.4	80.0	2.25	12.00	17.41	31.41	80.8	.727	23.6	418.8	3.6	.9	1.8	.8	.8	385.9
600.	200.0	1.60	13.4	40.0	2.25	12.00	11.01	25.01	75.5	.733	23.2	413.1	3.4	1.2	1.6	.9	.8	380.6
600.	200.0	1.60	13.4	60.0	2.25	12.00	14.30	28.30	78.0	.728	23.5	418.6	3.6	1.0	1.7	.9	.8	385.3
600.	200.0	1.60	13.4	80.0	2.25	12.00	17.38	31.38	80.8	.725	23.7	422.0	3.7	.9	1.8	.9	.8	388.1
600.	200.0	1.70	13.4	40.0	2.25	12.00	10.99	24.99	75.5	.732	23.3	415.7	3.5	1.2	1.5	1.1	.8	382.1
600.	200.0	1.70	13.4	60.0	2.25	12.00	14.28	28.28	78.0	.727	23.6	421.4	3.7	1.0	1.7	1.1	.8	386.8
600.	200.0	1.70	13.4	80.0	2.25	12.00	17.35	31.35	80.8	.724	23.8	424.9	3.8	.9	1.8	1.1	.8	389.6
600.	200.0	1.80	13.4	40.0	2.25	12.00	10.97	24.97	75.5	.731	23.4	418.1	3.6	1.2	1.5	1.3	.8	382.7
600.	200.0	1.80	13.4	60.0	2.25	12.00	14.25	28.25	78.0	.726	23.7	424.0	3.9	1.0	1.7	1.3	.8	387.5
600.	200.0	1.80	13.4	80.0	2.25	12.00	17.32	31.32	80.8	.723	23.9	427.6	4.0	.9	1.8	1.3	.8	390.3
600.	200.0	1.40	13.4	40.0	5.00	12.00	11.04	25.04	75.5	.736	14.9	406.7	3.2	1.2	1.6	.7	.7	376.7
600.	200.0	1.40	13.4	60.0	5.00	12.00	14.36	28.36	78.0	.731	15.1	411.8	3.3	1.0	1.7	.7	.7	381.2
600.	200.0	1.40	13.4	80.0	5.00	12.00	17.45	31.45	80.8	.728	15.2	415.0	3.4	.9	1.8	.7	.7	383.9
600.	200.0	1.50	13.4	40.0	5.00	12.00	11.02	25.02	75.5	.734	15.6	410.2	3.3	1.2	1.6	.8	.7	379.1
600.	200.0	1.50	13.4	60.0	5.00	12.00	14.33	28.33	78.0	.730	15.8	415.5	3.5	1.0	1.7	.8	.7	383.7
600.	200.0	1.50	13.4	80.0	5.00	12.00	17.41	31.41	80.8	.727	16.0	418.8	3.6	.9	1.8	.8	.7	386.4
600.	200.0	1.60	13.4	40.0	5.00	12.00	11.01	25.01	75.5	.733	16.4	413.1	3.4	1.2	1.6	.9	.7	380.9
600.	200.0	1.60	13.4	60.0	5.00	12.00	14.30	28.30	78.0	.728	16.6	418.6	3.6	1.0	1.7	.9	.7	385.5
600.	200.0	1.60	13.4	80.0	5.00	12.00	17.38	31.38	80.8	.725	16.7	422.0	3.7	.9	1.8	.9	.7	388.3
600.	200.0	1.70	13.4	40.0	5.00	12.00	10.99	24.99	75.5	.732	17.1	415.7	3.5	1.2	1.5	1.1	.8	382.1
600.	200.0	1.70	13.4	60.0	5.00	12.00	14.28	28.28	78.0	.727	17.3	421.4	3.7	1.0	1.7	1.1	.7	386.8
600.	200.0	1.70	13.4	80.0	5.00	12.00	17.35	31.35	80.8	.724	17.5	424.9	3.8	.9	1.8	1.1	.7	389.7
600.	200.0	1.80	13.4	40.0	5.00	12.00	10.97	24.97	75.5	.731	17.8	418.1	3.6	1.2	1.5	1.3	.8	382.5

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD
600.	200.0	1.80	13.4	60.0	5.00	12.00	14.25	28.25	78.0	.726	18.1	424.0	3.9	1.0	1.7	1.3	.8	387.3
600.	200.0	1.80	13.4	80.0	5.00	12.00	17.32	31.32	80.8	.723	18.3	427.6	4.0	.9	1.8	1.3	.8	390.1
600.	200.0	1.40	17.2	40.0	1.50	15.00	11.04	28.04	75.5	.736	34.6	406.7	3.2	1.2	1.6	1.0	.7	375.6
600.	200.0	1.40	17.2	60.0	1.50	15.00	14.36	31.36	78.0	.731	35.0	411.8	3.3	1.0	1.7	.9	.7	380.1
600.	200.0	1.40	17.2	80.0	1.50	15.00	17.45	34.45	80.8	.728	35.3	415.0	3.4	.9	1.8	.9	.7	382.8
600.	200.0	1.50	17.2	40.0	1.50	15.00	11.02	28.02	75.5	.734	34.7	410.2	3.3	1.2	1.6	1.1	.7	378.0
600.	200.0	1.50	17.2	60.0	1.50	15.00	14.33	31.33	78.0	.730	35.2	415.5	3.5	1.0	1.7	1.1	.7	382.5
600.	200.0	1.50	17.2	80.0	1.50	15.00	17.41	34.41	80.8	.727	35.4	418.8	3.6	.9	1.8	1.1	.7	385.3
600.	200.0	1.60	17.2	40.0	1.50	15.00	11.01	28.01	75.5	.733	34.8	413.1	3.4	1.2	1.6	1.3	.7	379.7
600.	200.0	1.60	17.2	60.0	1.50	15.00	14.30	31.30	78.0	.728	35.3	418.6	3.6	1.0	1.7	1.3	.6	384.4
600.	200.0	1.60	17.2	80.0	1.50	15.00	17.38	34.38	80.8	.725	35.6	422.0	3.7	.9	1.8	1.3	.6	387.2
600.	200.0	1.70	17.2	40.0	1.50	15.00	10.99	27.99	75.5	.732	34.9	415.7	3.5	1.2	1.5	1.6	.6	380.7
600.	200.0	1.70	17.2	60.0	1.50	15.00	14.28	31.28	78.0	.727	35.4	421.4	3.7	1.0	1.7	1.5	.6	385.4
600.	200.0	1.70	17.2	80.0	1.50	15.00	17.35	34.35	80.8	.724	35.7	424.9	3.8	.9	1.8	1.5	.6	388.3
600.	200.0	1.80	17.2	40.0	1.50	15.00	10.97	27.97	75.5	.731	35.0	418.1	3.6	1.2	1.5	1.9	.7	380.6
600.	200.0	1.80	17.2	60.0	1.50	15.00	14.25	31.25	78.0	.726	35.5	424.0	3.9	1.0	1.7	1.9	.7	385.4
600.	200.0	1.80	17.2	80.0	1.50	15.00	17.32	34.32	80.8	.723	35.8	427.6	4.0	.9	1.8	1.9	.7	388.2
600.	200.0	1.40	17.2	40.0	2.25	15.00	11.04	28.04	75.5	.736	23.1	406.7	3.2	1.2	1.6	1.0	.5	376.7
600.	200.0	1.40	17.2	60.0	2.25	15.00	14.36	31.36	78.0	.731	23.3	411.8	3.3	1.0	1.7	.9	.5	381.2
600.	200.0	1.40	17.2	80.0	2.25	15.00	17.45	34.45	80.8	.728	23.5	415.0	3.4	.9	1.8	.9	.5	383.9
600.	200.0	1.50	17.2	40.0	2.25	15.00	11.02	28.02	75.5	.734	23.1	410.2	3.3	1.2	1.6	1.1	.4	379.0
600.	200.0	1.50	17.2	60.0	2.25	15.00	14.33	31.33	78.0	.730	23.4	415.5	3.5	1.0	1.7	1.1	.4	383.6
600.	200.0	1.50	17.2	80.0	2.25	15.00	17.41	34.41	80.8	.727	23.6	418.8	3.6	.9	1.8	1.1	.4	386.3
600.	200.0	1.60	17.2	40.0	2.25	15.00	11.01	28.01	75.5	.733	23.2	413.1	3.4	1.2	1.6	1.3	.4	380.7
600.	200.0	1.60	17.2	60.0	2.25	15.00	14.30	31.30	78.0	.728	23.5	418.6	3.6	1.0	1.7	1.3	.4	385.4
600.	200.0	1.60	17.2	80.0	2.25	15.00	17.38	34.38	80.8	.725	23.7	422.0	3.7	.9	1.8	1.3	.4	388.2
600.	200.0	1.70	17.2	40.0	2.25	15.00	10.99	27.99	75.5	.732	23.3	415.7	3.5	1.2	1.5	1.6	.4	381.7
600.	200.0	1.70	17.2	60.0	2.25	15.00	14.28	31.28	78.0	.727	23.6	421.4	3.7	1.0	1.7	1.5	.4	386.4
600.	200.0	1.70	17.2	80.0	2.25	15.00	17.35	34.35	80.8	.724	23.8	424.9	3.8	.9	1.8	1.5	.4	389.3
600.	200.0	1.80	17.2	40.0	2.25	15.00	10.97	27.97	75.5	.731	23.4	418.1	3.6	1.2	1.5	1.9	.4	381.6
600.	200.0	1.80	17.2	60.0	2.25	15.00	14.25	31.25	78.0	.726	23.7	424.0	3.9	1.0	1.7	1.9	.4	386.4
600.	200.0	1.80	17.2	60.0	2.25	15.00	17.32	34.32	80.8	.723	23.9	427.6	4.0	.9	1.8	1.9	.4	389.2
600.	200.0	1.40	17.2	40.0	5.00	15.00	11.04	28.04	75.5	.736	15.6	406.7	3.2	1.2	1.6	1.0	.4	376.9
600.	200.0	1.40	17.2	60.0	5.00	15.00	14.36	31.36	78.0	.731	15.8	411.8	3.3	1.0	1.7	.9	.4	381.4
600.	200.0	1.40	17.2	80.0	5.00	15.00	17.45	34.45	80.8	.728	15.9	415.0	3.4	.9	1.8	.9	.4	384.1
600.	200.0	1.50	17.2	40.0	5.00	15.00	11.02	28.02	75.5	.734	16.4	410.2	3.3	1.2	1.6	1.1	.4	379.0
600.	200.0	1.50	17.2	60.0	5.00	15.00	14.33	31.33	78.0	.730	16.6	415.5	3.5	1.0	1.7	1.1	.4	383.6
600.	200.0	1.50	17.2	80.0	5.00	15.00	17.41	34.41	80.8	.727	16.7	418.8	3.6	.9	1.8	1.1	.4	386.4
600.	200.0	1.60	17.2	40.0	5.00	15.00	11.01	28.01	75.5	.733	17.1	413.1	3.4	1.2	1.6	1.3	.4	380.6
600.	200.0	1.60	17.2	60.0	5.00	15.00	14.30	31.30	78.0	.728	17.4	418.6	3.6	1.0	1.7	1.3	.4	385.3

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%ERL	ISPD
ENGLISH UNITS - SEE NOMENCLATURE LIST																		
600.	200.0	1.60	17.2	80.0	5.00	15.00	17.38	34.38	80.8	.725	17.5	422.0	3.7	.9	1.8	1.3	.4	388.1
600.	200.0	1.70	17.2	40.0	5.00	15.00	10.99	27.99	75.5	.732	17.9	415.7	3.5	1.2	1.5	1.6	.5	381.4
600.	200.0	1.70	17.2	60.0	5.00	15.00	14.28	31.28	78.0	.727	18.2	421.4	3.7	1.0	1.7	1.5	.5	386.2
600.	200.0	1.70	17.2	80.0	5.00	15.00	17.35	34.35	80.8	.724	18.3	424.9	3.8	.9	1.8	1.5	.5	389.0
600.	200.0	1.80	17.2	40.0	5.00	15.00	10.97	27.97	75.5	.731	18.7	418.1	3.6	1.2	1.5	1.9	.5	381.2
600.	200.0	1.80	17.2	60.0	5.00	15.00	14.25	31.25	78.0	.726	18.9	424.0	3.9	1.0	1.7	1.9	.5	386.0
600.	200.0	1.80	17.2	80.0	5.00	15.00	17.32	34.32	80.8	.723	19.1	427.6	4.0	.9	1.8	1.9	.5	388.8

APPENDIX A

TABLE SET B

BIMODAL ENGINE PERFORMANCE TABULATION

A E R O J E T L I Q U I D R O C K E T C O M P A N Y

FLUORINE/HYDRAZINE ENGINE COMPARISON STUDY

***** BIMODAL ENGINE DATA *****

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%ERL	ISPD
600.	80.0	1.40	5.0	40.0	1.50	6.00	17.39	26.39	75.5	1.159	4.1	405.4	5.0	1.2	1.7	.3	.5	370.4
600.	80.0	1.40	5.0	60.0	1.50	6.00	22.61	31.61	78.0	1.151	4.2	410.8	5.3	1.0	1.8	.3	.5	374.2
600.	80.0	1.40	5.0	80.0	1.50	6.00	27.47	36.47	80.8	1.147	4.2	414.1	5.5	.9	2.0	.3	.5	376.6
600.	80.0	1.50	5.0	40.0	1.50	6.00	17.36	26.36	75.5	1.157	4.2	408.7	5.1	1.2	1.7	.2	.8	371.8
600.	80.0	1.50	5.0	60.0	1.50	6.00	22.56	31.56	78.0	1.149	4.2	414.3	5.5	1.0	1.8	.2	.8	375.7
600.	80.0	1.50	5.0	80.0	1.50	6.00	27.41	36.41	80.8	1.144	4.2	417.7	5.7	.9	1.9	.2	.8	378.2
600.	80.0	1.60	5.0	40.0	1.50	6.00	17.33	26.33	75.5	1.155	4.2	411.6	5.2	1.2	1.7	.3	1.0	373.1
600.	80.0	1.60	5.0	60.0	1.50	6.00	22.52	31.52	78.0	1.147	4.2	417.3	5.5	1.0	1.8	.3	1.0	377.1
600.	80.0	1.60	5.0	80.0	1.50	6.00	27.36	36.36	80.8	1.142	4.3	420.9	5.7	.9	1.9	.3	1.0	379.6
600.	80.0	1.70	5.0	40.0	1.50	6.00	17.31	26.31	75.5	1.153	4.2	414.1	5.3	1.2	1.7	.4	1.3	373.2
600.	80.0	1.70	5.0	60.0	1.50	6.00	22.49	31.49	78.0	1.145	4.2	420.0	5.6	1.0	1.8	.4	1.3	377.3
600.	80.0	1.70	5.0	80.0	1.50	6.00	27.31	36.31	80.8	1.140	4.3	423.7	5.9	.9	1.9	.4	1.3	379.8
600.	80.0	1.80	5.0	40.0	1.50	6.00	17.28	26.28	75.5	1.151	4.2	416.3	5.5	1.2	1.7	.6	1.5	372.6
600.	80.0	1.80	5.0	60.0	1.50	6.00	22.44	31.44	78.0	1.143	4.3	422.4	5.9	1.0	1.8	.6	1.5	376.6
600.	80.0	1.80	5.0	80.0	1.50	6.00	27.26	36.26	80.8	1.138	4.3	426.2	6.1	.8	1.9	.6	1.5	379.2
600.	80.0	1.40	5.0	40.0	2.50	6.00	17.39	26.39	75.5	1.159	2.5	405.4	5.0	1.2	1.7	.3	.5	370.4
600.	80.0	1.40	5.0	60.0	2.50	6.00	22.61	31.61	78.0	1.151	2.5	410.8	5.3	1.0	1.8	.3	.5	374.2
600.	80.0	1.40	5.0	80.0	2.50	6.00	27.47	36.47	80.8	1.147	2.5	414.1	5.5	.9	2.0	.3	.5	376.6
600.	80.0	1.50	5.0	40.0	2.50	6.00	17.36	26.36	75.5	1.157	2.5	408.7	5.1	1.2	1.7	.2	.8	371.8
600.	80.0	1.50	5.0	60.0	2.50	6.00	22.56	31.56	78.0	1.149	2.5	414.3	5.5	1.0	1.8	.2	.8	375.7
600.	80.0	1.50	5.0	80.0	2.50	6.00	27.41	36.41	80.8	1.144	2.5	417.7	5.7	.9	1.9	.2	.8	378.2
600.	80.0	1.60	5.0	40.0	2.50	6.00	17.33	26.33	75.5	1.155	2.5	411.6	5.2	1.2	1.7	.3	1.0	373.1
600.	80.0	1.60	5.0	60.0	2.50	6.00	22.52	31.52	78.0	1.147	2.5	417.3	5.5	1.0	1.8	.3	1.0	377.1
600.	80.0	1.60	5.0	80.0	2.50	6.00	27.36	36.36	80.8	1.142	2.6	420.9	5.7	.9	1.9	.3	1.0	379.6
600.	80.0	1.70	5.0	40.0	2.50	6.00	17.31	26.31	75.5	1.153	2.5	414.1	5.3	1.2	1.7	.4	1.3	373.2
600.	80.0	1.70	5.0	60.0	2.50	6.00	22.49	31.49	78.0	1.145	2.5	420.0	5.6	1.0	1.8	.4	1.3	377.3
600.	80.0	1.70	5.0	80.0	2.50	6.00	27.31	36.31	80.8	1.140	2.6	423.7	5.9	.9	1.9	.4	1.3	379.8
600.	80.0	1.80	5.0	40.0	2.50	6.00	17.28	26.28	75.5	1.151	2.5	416.3	5.5	1.2	1.7	.6	1.5	372.6
600.	80.0	1.80	5.0	60.0	2.50	6.00	22.44	31.44	78.0	1.143	2.6	422.4	5.9	1.0	1.8	.6	1.5	376.6
600.	80.0	1.80	5.0	80.0	2.50	6.00	27.26	36.26	80.8	1.138	2.6	426.2	6.1	.8	1.9	.6	1.5	379.2
600.	80.0	1.40	5.0	40.0	5.00	6.00	17.39	26.39	75.5	1.159	2.4	405.4	5.0	1.2	1.7	.3	.5	370.4
600.	80.0	1.40	5.0	60.0	5.00	6.00	22.61	31.61	78.0	1.151	2.5	410.8	5.3	1.0	1.8	.3	.5	374.2
600.	80.0	1.40	5.0	80.0	5.00	6.00	27.47	35.47	80.8	1.147	2.5	414.1	5.5	.9	2.0	.3	.5	376.6
600.	80.0	1.50	5.0	40.0	5.00	6.00	17.36	26.36	75.5	1.157	2.4	408.7	5.1	1.2	1.7	.2	.8	371.8
600.	80.0	1.50	5.0	60.0	5.00	6.00	22.56	31.56	78.0	1.149	2.4	414.3	5.5	1.0	1.8	.2	.8	375.7
600.	80.0	1.50	5.0	80.0	5.00	6.00	27.41	36.41	80.8	1.144	2.5	417.7	5.7	.9	1.9	.2	.8	378.2
600.	80.0	1.60	5.0	40.0	5.00	6.00	17.33	26.33	75.5	1.155	2.4	411.6	5.2	1.2	1.7	.3	1.0	373.1
600.	80.0	1.60	5.0	60.0	5.00	6.00	22.52	31.52	78.0	1.147	2.4	417.3	5.5	1.0	1.8	.3	1.0	377.1

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD
600.	80.0	1.60	5.0	80.0	5.00	6.00	27.36	36.36	80.8	1.142	2.4	420.9	5.7	.9	1.9	.3	1.0	379.6
600.	80.0	1.70	5.0	40.0	5.00	6.00	17.31	26.31	75.5	1.153	2.3	414.1	5.3	1.2	1.7	.4	1.3	373.2
600.	80.0	1.70	5.0	60.0	5.00	6.00	22.49	31.49	78.0	1.145	2.3	420.0	5.6	1.0	1.8	.4	1.3	377.3
600.	80.0	1.70	5.0	80.0	5.00	6.00	27.31	36.31	80.8	1.140	2.4	423.7	5.9	.9	1.9	.4	1.3	379.8
600.	80.0	1.80	5.0	40.0	5.00	6.00	17.28	26.28	75.5	1.151	2.3	416.3	5.5	1.2	1.7	.6	1.5	372.6
600.	80.0	1.80	5.0	60.0	5.00	6.00	22.44	31.44	78.0	1.143	2.3	422.4	5.9	1.0	1.8	.6	1.5	376.6
600.	80.0	1.80	5.0	80.0	5.00	6.00	27.26	36.26	80.8	1.138	2.3	426.2	6.1	.8	1.9	.6	1.5	379.2
600.	80.0	1.40	13.4	40.0	1.50	12.00	17.39	32.39	75.5	1.159	4.1	405.4	5.0	1.2	1.7	.7	.5	368.7
600.	80.0	1.40	13.4	60.0	1.50	12.00	22.61	37.61	78.0	1.151	4.2	410.8	5.3	1.0	1.8	.7	.5	372.6
600.	80.0	1.40	13.4	80.0	1.50	12.00	27.47	42.47	80.8	1.147	4.2	414.1	5.5	.9	2.0	.6	.5	375.0
600.	80.0	1.50	13.4	40.0	1.50	12.00	17.36	32.36	75.5	1.157	4.2	408.7	5.1	1.2	1.7	.8	.8	369.6
600.	80.0	1.50	13.4	60.0	1.50	12.00	22.56	37.56	78.0	1.149	4.2	414.3	5.5	1.0	1.8	.7	.8	373.6
600.	80.0	1.50	13.4	80.0	1.50	12.00	27.41	42.41	80.8	1.144	4.2	417.7	5.7	.9	1.9	.7	.8	376.1
600.	80.0	1.60	13.4	40.0	1.50	12.00	17.33	32.33	75.5	1.155	4.2	411.6	5.2	1.2	1.7	1.1	1.0	369.8
600.	80.0	1.60	13.4	60.0	1.50	12.00	22.52	37.52	78.0	1.147	4.2	417.3	5.5	1.0	1.8	1.1	1.0	373.8
600.	80.0	1.60	13.4	80.0	1.50	12.00	27.36	42.36	80.8	1.142	4.3	420.9	5.7	.9	1.9	1.0	1.0	376.3
600.	80.0	1.70	13.4	40.0	1.50	12.00	17.31	32.31	75.5	1.153	4.2	414.1	5.3	1.2	1.7	1.6	1.3	368.4
600.	80.0	1.70	13.4	60.0	1.50	12.00	22.49	37.49	78.0	1.145	4.2	420.0	5.6	1.0	1.8	1.6	1.3	372.4
600.	80.0	1.70	13.4	80.0	1.50	12.00	27.31	42.31	80.8	1.140	4.3	423.7	5.9	.8	1.9	1.6	1.3	374.9
600.	80.0	1.80	13.4	40.0	1.50	12.00	17.28	32.28	75.5	1.151	4.2	416.3	5.5	1.1	1.7	2.1	1.5	366.6
600.	80.0	1.80	13.4	60.0	1.50	12.00	22.44	37.44	78.0	1.143	4.3	422.4	5.9	1.0	1.8	2.1	1.5	370.5
600.	80.0	1.80	13.4	80.0	1.50	12.00	27.26	42.26	80.8	1.138	4.3	426.2	6.1	.8	1.9	2.1	1.5	372.9
600.	80.0	1.40	13.4	40.0	2.50	12.00	17.39	32.39	75.5	1.159	2.5	405.4	5.0	1.2	1.7	.7	.5	368.7
600.	80.0	1.40	13.4	60.0	2.50	12.00	22.61	37.61	78.0	1.151	2.5	410.8	5.3	1.0	1.8	.7	.5	372.6
600.	80.0	1.40	13.4	80.0	2.50	12.00	27.47	42.47	80.8	1.147	2.5	414.1	5.5	.9	2.0	.6	.5	375.0
600.	80.0	1.50	13.4	40.0	2.50	12.00	17.36	32.36	75.5	1.157	2.5	408.7	5.1	1.2	1.7	.8	.8	369.6
600.	80.0	1.50	13.4	60.0	2.50	12.00	22.56	37.56	78.0	1.149	2.5	414.3	5.5	1.0	1.8	.7	.8	373.6
600.	80.0	1.50	13.4	80.0	2.50	12.00	27.41	42.41	80.8	1.144	2.5	417.7	5.7	.9	1.9	.7	.8	376.1
600.	80.0	1.60	13.4	40.0	2.50	12.00	17.33	32.33	75.5	1.155	2.5	411.6	5.2	1.2	1.7	1.1	1.0	369.8
600.	80.0	1.60	13.4	60.0	2.50	12.00	22.52	37.52	78.0	1.147	2.5	417.3	5.5	1.0	1.8	1.1	1.0	373.8
600.	80.0	1.60	13.4	80.0	2.50	12.00	27.36	42.36	80.8	1.142	2.6	420.9	5.7	.9	1.9	1.0	1.0	376.3
600.	80.0	1.70	13.4	40.0	2.50	12.00	17.31	32.31	75.5	1.153	2.5	414.1	5.3	1.2	1.7	1.6	1.3	368.4
600.	80.0	1.70	13.4	60.0	2.50	12.00	22.49	37.49	78.0	1.145	2.5	420.0	5.6	1.0	1.8	1.6	1.3	372.4
600.	80.0	1.70	13.4	80.0	2.50	12.00	27.31	42.31	80.8	1.140	2.6	423.7	5.9	.8	1.9	1.6	1.3	374.9
600.	60.0	1.80	13.4	40.0	2.50	12.00	17.28	32.28	75.5	1.151	2.5	416.3	5.5	1.1	1.7	2.1	1.5	366.6
600.	80.0	1.80	13.4	60.0	2.50	12.00	22.44	37.44	78.0	1.143	2.6	422.4	5.9	1.0	1.8	2.1	1.5	370.5
600.	80.0	1.80	13.4	80.0	2.50	12.00	27.26	42.26	80.8	1.138	2.6	426.2	6.1	.8	1.9	2.1	1.5	372.9
600.	80.0	1.40	13.4	40.0	5.00	12.00	17.39	32.39	75.5	1.159	2.4	405.4	5.0	1.2	1.7	.7	.5	368.7
600.	80.0	1.40	13.4	60.0	5.00	12.00	22.61	37.61	78.0	1.151	2.5	410.8	5.3	1.0	1.8	.7	.5	372.6
600.	80.0	1.40	13.4	80.0	5.00	12.00	27.47	42.47	80.8	1.147	2.5	414.1	5.5	.9	2.0	.6	.5	375.0

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD
600.	80.0	1.50	13.4	40.0	5.00	12.00	17.36	32.36	75.5	1.157	2.4	408.7	5.1	1.2	1.7	.8	.8	369.6
600.	80.0	1.50	13.4	60.0	5.00	12.00	22.56	37.56	78.0	1.149	2.4	414.3	5.5	1.0	1.8	.7	.8	373.6
600.	80.0	1.50	13.4	80.0	5.00	12.00	27.41	42.41	80.8	1.144	2.5	417.7	5.7	.9	1.9	.7	.8	376.1
600.	80.0	1.60	13.4	40.0	5.00	12.00	17.33	32.33	75.5	1.155	2.4	411.6	5.2	1.2	1.7	1.1	1.0	369.8
600.	80.0	1.60	13.4	60.0	5.00	12.00	22.52	37.52	78.0	1.147	2.4	417.3	5.5	1.0	1.8	1.1	1.0	373.8
600.	80.0	1.60	13.4	80.0	5.00	12.00	27.36	42.36	80.8	1.142	2.4	420.9	5.7	.9	1.9	1.0	1.0	376.3
600.	80.0	1.70	13.4	40.0	5.00	12.00	17.31	32.31	75.5	1.153	2.3	414.1	5.3	1.2	1.7	1.6	1.3	368.4
600.	80.0	1.70	13.4	60.0	5.00	12.00	22.49	37.49	78.0	1.145	2.3	420.0	5.6	1.0	1.8	1.6	1.3	372.4
600.	80.0	1.70	13.4	80.0	5.00	12.00	27.31	42.31	80.8	1.140	2.4	423.7	5.9	.8	1.9	1.6	1.3	374.9
600.	80.0	1.80	13.4	40.0	5.00	12.00	17.28	32.28	75.5	1.151	2.3	416.3	5.5	1.1	1.7	2.1	1.5	366.6
600.	80.0	1.80	13.4	60.0	5.00	12.00	22.44	37.44	78.0	1.143	2.3	422.4	5.9	1.0	1.8	2.1	1.5	370.5
600.	80.0	1.80	13.4	80.0	5.00	12.00	27.26	42.26	80.8	1.138	2.3	426.2	6.1	.8	1.9	2.1	1.5	372.9
600.	80.0	1.40	17.2	40.0	1.50	15.00	17.39	35.39	75.5	1.159	4.1	405.4	5.0	1.2	1.7	1.0	.5	367.7
600.	80.0	1.40	17.2	60.0	1.50	15.00	22.61	40.61	78.0	1.151	4.2	410.8	5.3	1.0	1.8	.9	.5	371.6
600.	80.0	1.40	17.2	80.0	1.50	15.00	27.47	45.47	80.8	1.147	4.2	414.1	5.5	.9	2.0	.9	.5	374.1
600.	80.0	1.50	17.2	40.0	1.50	15.00	17.36	35.36	75.5	1.157	4.2	408.7	5.1	1.2	1.7	1.2	.8	368.0
600.	80.0	1.50	17.2	60.0	1.50	15.00	22.56	40.56	78.0	1.149	4.2	414.3	5.5	1.0	1.8	1.1	.8	372.0
600.	80.0	1.50	17.2	80.0	1.50	15.00	27.41	45.41	80.8	1.144	4.2	417.7	5.7	.9	1.9	1.1	.8	374.5
600.	80.0	1.60	17.2	40.0	1.50	15.00	17.33	35.33	75.5	1.155	4.2	411.6	5.2	1.2	1.7	1.7	1.0	367.4
600.	80.0	1.60	17.2	60.0	1.50	15.00	22.52	40.52	78.0	1.147	4.2	417.3	5.5	1.0	1.8	1.7	1.0	371.4
600.	80.0	1.60	17.2	80.0	1.50	15.00	27.36	45.36	80.8	1.142	4.3	420.9	5.7	.8	1.9	1.6	1.0	373.9
600.	80.0	1.70	17.2	40.0	1.50	15.00	17.31	35.31	75.5	1.153	4.2	414.1	5.3	1.1	1.7	2.3	1.3	365.4
600.	80.0	1.70	17.2	60.0	1.50	15.00	22.49	40.49	78.0	1.145	4.2	420.0	5.6	1.0	1.8	2.3	1.3	369.3
600.	80.0	1.70	17.2	80.0	1.50	15.00	27.31	45.31	80.8	1.140	4.3	423.7	5.9	.8	1.9	2.3	1.3	371.8
600.	80.0	1.80	17.2	40.0	1.50	15.00	17.28	35.28	75.5	1.151	4.2	416.3	5.5	1.1	1.7	2.9	1.5	363.2
600.	80.0	1.80	17.2	60.0	1.50	15.00	22.44	40.44	78.0	1.143	4.3	422.4	5.9	1.0	1.8	2.9	1.5	367.1
600.	80.0	1.80	17.2	80.0	1.50	15.00	27.26	45.26	80.8	1.138	4.3	426.2	6.1	.8	1.9	2.9	1.5	369.4
600.	80.0	1.40	17.2	40.0	2.50	15.00	17.39	35.39	75.5	1.159	2.5	405.4	5.0	1.2	1.7	1.0	.5	367.7
600.	80.0	1.40	17.2	60.0	2.50	15.00	22.61	40.61	78.0	1.151	2.5	410.8	5.3	1.0	1.8	.9	.5	371.6
600.	80.0	1.40	17.2	80.0	2.50	15.00	27.47	45.47	80.8	1.147	2.5	414.1	5.5	.9	2.0	.9	.5	374.1
600.	80.0	1.50	17.2	40.0	2.50	15.00	17.36	35.36	75.5	1.157	2.5	408.7	5.1	1.2	1.7	1.2	.8	368.0
600.	80.0	1.50	17.2	60.0	2.50	15.00	22.56	40.56	78.0	1.149	2.5	414.3	5.5	1.0	1.8	1.1	.8	372.0
600.	80.0	1.50	17.2	80.0	2.50	15.00	27.41	45.41	80.8	1.144	2.5	417.7	5.7	.9	1.9	1.1	.8	374.5
600.	80.0	1.60	17.2	40.0	2.50	15.00	17.33	35.33	75.5	1.155	2.5	411.6	5.2	1.2	1.7	1.7	1.0	367.4
600.	80.0	1.60	17.2	60.0	2.50	15.00	22.52	40.52	78.0	1.147	2.5	417.3	5.5	1.0	1.8	1.7	1.0	371.4
600.	80.0	1.60	17.2	80.0	2.50	15.00	27.36	45.36	80.8	1.142	2.6	420.9	5.7	.8	1.9	1.6	1.0	373.9
600.	80.0	1.70	17.2	40.0	2.50	15.00	17.31	35.31	75.5	1.153	2.5	414.1	5.3	1.1	1.7	2.3	1.3	365.4
600.	80.0	1.70	17.2	60.0	2.50	15.00	22.49	40.49	78.0	1.145	2.5	420.0	5.6	1.0	1.8	2.3	1.3	369.3
600.	80.0	1.70	17.2	80.0	2.50	15.00	27.31	45.31	80.8	1.140	2.6	423.7	5.9	.8	1.9	2.3	1.3	371.8
600.	80.0	1.80	17.2	40.0	2.50	15.00	17.28	35.28	75.5	1.151	2.5	416.3	5.5	1.1	1.7	2.9	1.5	363.2

236

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD

ENGLISH UNITS - SEE NOMENCLATURE LIST

600.	80.0	1.80	17.2	60.0	2.50	15.00	22.44	40.44	78.0	1.143	2.6	422.4	5.9	1.0	1.8	2.9	1.5	367.1
600.	80.0	1.80	17.2	80.0	2.50	15.00	27.26	45.26	80.8	1.138	2.6	426.2	6.1	.8	1.9	2.9	1.5	369.4
600.	80.0	1.40	17.2	40.0	5.00	15.00	17.39	35.39	75.5	1.159	2.4	405.4	5.0	1.2	1.7	1.0	.5	367.7
600.	80.0	1.40	17.2	60.0	5.00	15.00	22.61	40.61	78.0	1.151	2.5	410.8	5.3	1.0	1.8	.9	.5	371.6
600.	80.0	1.40	17.2	80.0	5.00	15.00	27.47	45.47	80.8	1.147	2.5	414.1	5.5	.9	2.0	.9	.5	374.1
600.	80.0	1.50	17.2	40.0	5.00	15.00	17.36	35.36	75.5	1.157	2.4	408.7	5.1	1.2	1.7	1.2	.8	368.0
600.	80.0	1.50	17.2	60.0	5.00	15.00	22.56	40.56	78.0	1.149	2.4	414.3	5.5	1.0	1.8	1.1	.8	372.0
600.	80.0	1.50	17.2	80.0	5.00	15.00	27.41	45.41	80.8	1.144	2.5	417.7	5.7	.9	1.9	1.1	.8	374.5
600.	80.0	1.60	17.2	40.0	5.00	15.00	17.33	35.33	75.5	1.155	2.4	411.6	5.2	1.2	1.7	1.7	1.0	367.4
600.	80.0	1.60	17.2	60.0	5.00	15.00	22.52	40.52	78.0	1.147	2.4	417.3	5.5	1.0	1.8	1.7	1.0	371.4
600.	80.0	1.60	17.2	80.0	5.00	15.00	27.36	45.36	80.8	1.142	2.4	420.9	5.7	.8	1.9	1.6	1.0	373.9
600.	80.0	1.70	17.2	40.0	5.00	15.00	17.31	35.31	75.5	1.153	2.3	414.1	5.3	1.1	1.7	2.3	1.3	365.4
600.	80.0	1.70	17.2	60.0	5.00	15.00	22.49	40.49	78.0	1.145	2.3	420.0	5.6	1.0	1.8	2.3	1.3	369.3
600.	80.0	1.70	17.2	80.0	5.00	15.00	27.31	45.31	80.8	1.140	2.4	423.7	5.9	.8	1.9	2.3	1.3	371.9
600.	80.0	1.80	17.2	40.0	5.00	15.00	17.28	35.28	75.5	1.151	2.3	416.3	5.5	1.1	1.7	2.9	1.5	363.2
600.	80.0	1.80	17.2	60.0	5.00	15.00	22.44	40.44	78.0	1.143	2.3	422.4	5.9	1.0	1.8	2.9	1.5	367.1
600.	80.0	1.80	17.2	80.0	5.00	15.00	27.26	45.26	80.8	1.138	2.3	426.2	6.1	.8	1.9	2.9	1.5	369.4
600.	120.0	1.40	5.0	40.0	1.50	6.00	14.23	23.23	75.5	.948	6.2	406.0	4.1	1.2	1.6	.3	.5	374.9
600.	120.0	1.40	5.0	60.0	1.50	6.00	18.49	27.49	78.0	.942	6.3	411.3	4.3	1.0	1.8	.3	.5	379.1
600.	120.0	1.40	5.0	80.0	1.50	6.00	22.47	31.47	80.8	.938	6.3	414.5	4.4	.9	1.9	.3	.5	381.6
600.	120.0	1.50	5.0	40.0	1.50	6.00	14.20	23.20	75.5	.946	6.2	409.4	4.2	1.2	1.6	.3	.8	376.4
600.	120.0	1.50	5.0	60.0	1.50	6.00	18.45	27.45	78.0	.940	6.3	414.9	4.4	1.0	1.8	.2	.8	380.6
600.	120.0	1.50	5.0	80.0	1.50	6.00	22.42	31.42	80.8	.936	6.3	418.2	4.6	.9	1.9	.2	.8	383.1
600.	120.0	1.60	5.0	40.0	1.50	6.00	14.18	23.18	75.5	.945	6.2	412.3	4.3	1.2	1.6	.3	1.0	377.8
600.	120.0	1.60	5.0	60.0	1.50	6.00	18.42	27.42	78.0	.938	6.3	417.9	4.5	1.0	1.8	.3	1.0	382.0
600.	120.0	1.60	5.0	80.0	1.50	6.00	22.38	31.38	80.8	.934	6.4	421.4	4.7	.9	1.9	.3	1.0	384.6
600.	120.0	1.70	5.0	40.0	1.50	6.00	14.16	23.16	75.5	.943	6.2	414.8	4.4	1.2	1.6	.4	1.3	378.1
600.	120.0	1.70	5.0	60.0	1.50	6.00	18.39	27.39	78.0	.937	6.3	420.6	4.7	1.0	1.8	.4	1.3	382.3
600.	120.0	1.70	5.0	80.0	1.50	6.00	22.34	31.34	80.8	.933	6.4	424.3	4.9	.9	1.9	.4	1.3	385.0
600.	120.0	1.80	5.0	40.0	1.50	6.00	14.13	23.13	75.5	.942	6.3	417.1	4.6	1.2	1.6	.5	1.5	378.0
600.	120.0	1.80	5.0	60.0	1.50	6.00	18.36	27.36	78.0	.935	6.4	423.1	4.9	1.0	1.8	.5	1.5	382.3
600.	120.0	1.80	5.0	80.0	1.50	6.00	22.30	31.30	80.8	.931	6.4	426.9	5.1	.9	1.9	.5	1.5	384.9
600.	120.0	1.40	5.0	40.0	2.50	6.00	14.23	23.23	75.5	.948	3.7	406.0	4.1	1.2	1.6	.3	.5	374.9
600.	120.0	1.40	5.0	60.0	2.50	6.00	18.49	27.49	78.0	.942	3.8	411.3	4.3	1.0	1.8	.3	.5	379.1
600.	120.0	1.40	5.0	80.0	2.50	6.00	22.47	31.47	80.8	.938	3.8	414.5	4.4	.9	1.9	.3	.5	381.6
600.	120.0	1.50	5.0	40.0	2.50	6.00	14.20	23.20	75.5	.946	3.7	409.4	4.2	1.2	1.6	.3	.8	376.4
600.	120.0	1.50	5.0	60.0	2.50	6.00	18.45	27.45	78.0	.940	3.8	414.9	4.4	1.0	1.8	.2	.8	380.6
600.	120.0	1.50	5.0	80.0	2.50	6.00	22.42	31.42	80.8	.936	3.8	418.2	4.6	.9	1.9	.2	.8	383.1
600.	120.0	1.60	5.0	40.0	2.50	6.00	14.18	23.18	75.5	.945	3.7	412.3	4.3	1.2	1.6	.3	1.0	377.8
600.	120.0	1.60	5.0	60.0	2.50	6.00	18.42	27.42	78.0	.938	3.8	417.9	4.5	1.0	1.8	.3	1.0	382.0

237

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD
600.	120.0	1.60	5.0	80.0	2.50	6.00	22.38	31.38	80.8	.934	3.8	421.4	4.7	.9	1.9	.3	1.0	384.6
600.	120.0	1.70	5.0	40.0	2.50	6.00	14.16	23.16	75.5	.943	3.7	414.8	4.4	1.2	1.6	.4	1.3	378.1
600.	120.0	1.70	5.0	60.0	2.50	6.00	18.39	27.39	78.0	.937	3.8	420.6	4.7	1.0	1.8	.4	1.3	382.3
600.	120.0	1.70	5.0	80.0	2.50	6.00	22.34	31.34	80.8	.933	3.8	424.3	4.9	.9	1.9	.4	1.3	385.0
600.	120.0	1.80	5.0	40.0	2.50	6.00	14.13	23.13	75.5	.942	3.8	417.1	4.6	1.2	1.6	.5	1.5	378.0
600.	120.0	1.80	5.0	60.0	2.50	6.00	18.36	27.36	78.0	.935	3.8	423.1	4.9	1.0	1.8	.5	1.5	382.3
600.	120.0	1.80	5.0	80.0	2.50	6.00	22.30	31.30	80.8	.931	3.8	426.9	5.1	.9	1.9	.5	1.5	384.9
600.	120.0	1.40	5.0	40.0	5.00	6.00	14.23	23.23	75.5	.948	3.0	406.0	4.1	1.2	1.6	.3	.5	374.9
600.	120.0	1.40	5.0	60.0	5.00	6.00	18.49	27.49	78.0	.942	3.0	411.3	4.3	1.0	1.8	.3	.5	379.1
600.	120.0	1.40	5.0	80.0	5.00	6.00	22.47	31.47	80.8	.938	3.1	414.5	4.4	.9	1.9	.3	.5	381.6
600.	120.0	1.50	5.0	40.0	5.00	6.00	14.20	23.20	75.5	.946	2.9	409.4	4.2	1.2	1.6	.3	.8	376.4
600.	120.0	1.50	5.0	60.0	5.00	6.00	18.45	27.45	78.0	.940	3.0	414.9	4.4	1.0	1.8	.2	.8	380.6
600.	120.0	1.50	5.0	80.0	5.00	6.00	22.42	31.42	80.8	.936	3.0	418.2	4.6	.9	1.9	.2	.8	383.1
600.	120.0	1.60	5.0	40.0	5.00	6.00	14.18	23.18	75.5	.945	2.9	412.3	4.3	1.2	1.6	.3	1.0	377.8
600.	120.0	1.60	5.0	60.0	5.00	6.00	18.42	27.42	78.0	.938	2.9	417.9	4.5	1.0	1.8	.3	1.0	382.0
600.	120.0	1.60	5.0	80.0	5.00	6.00	22.38	31.38	80.8	.934	3.0	421.4	4.7	.9	1.9	.3	1.0	384.6
600.	120.0	1.70	5.0	40.0	5.00	6.00	14.16	23.16	75.5	.943	2.8	414.8	4.4	1.2	1.6	.4	1.3	378.1
600.	120.0	1.70	5.0	60.0	5.00	6.00	18.39	27.39	78.0	.937	2.9	420.6	4.7	1.0	1.8	.4	1.3	382.3
600.	120.0	1.70	5.0	80.0	5.00	6.00	22.34	31.34	80.8	.933	2.9	424.3	4.9	.9	1.9	.4	1.3	385.0
600.	120.0	1.80	5.0	40.0	5.00	6.00	14.13	23.13	75.5	.942	2.8	417.1	4.6	1.2	1.6	.5	1.5	378.0
600.	120.0	1.80	5.0	60.0	5.00	6.00	18.36	27.36	78.0	.935	2.8	423.1	4.9	1.0	1.8	.5	1.5	382.3
600.	120.0	1.80	5.0	80.0	5.00	6.00	22.30	31.30	80.8	.931	2.9	426.9	5.1	.9	1.9	.5	1.5	384.9
600.	120.0	1.40	13.4	40.0	1.50	12.00	14.23	29.23	75.5	.948	6.2	406.0	4.1	1.2	1.6	.7	.5	373.1
600.	120.0	1.40	13.4	60.0	1.50	12.00	18.49	33.49	78.0	.942	6.3	411.3	4.3	1.0	1.8	.7	.5	377.3
600.	120.0	1.40	13.4	80.0	1.50	12.00	22.47	37.47	80.8	.938	6.3	414.5	4.4	.9	1.9	.7	.5	379.9
600.	120.0	1.50	13.4	40.0	1.50	12.00	14.20	29.20	75.5	.946	6.2	409.4	4.2	1.2	1.6	.8	.8	374.2
600.	120.0	1.50	13.4	60.0	1.50	12.00	18.45	33.45	78.0	.940	6.3	414.9	4.4	1.0	1.8	.8	.8	378.4
600.	120.0	1.50	13.4	80.0	1.50	12.00	22.42	37.42	80.8	.936	6.3	418.2	4.6	.9	1.9	.7	.8	381.0
600.	120.0	1.60	13.4	40.0	1.50	12.00	14.18	29.18	75.5	.945	6.2	412.3	4.3	1.2	1.6	1.0	1.0	374.8
600.	120.0	1.60	13.4	60.0	1.50	12.00	18.42	33.42	78.0	.938	6.3	417.9	4.5	1.0	1.8	1.0	1.0	379.0
600.	120.0	1.60	13.4	80.0	1.50	12.00	22.38	37.38	80.8	.934	6.4	421.4	4.7	.9	1.9	1.0	1.0	381.6
600.	120.0	1.70	13.4	40.0	1.50	12.00	14.16	29.16	75.5	.943	6.2	414.8	4.4	1.2	1.6	1.4	1.3	374.1
600.	120.0	1.70	13.4	60.0	1.50	12.00	18.39	33.39	78.0	.937	6.3	420.6	4.7	1.0	1.8	1.4	1.3	378.3
600.	120.0	1.70	13.4	80.0	1.50	12.00	22.34	37.34	80.8	.933	6.4	424.3	4.9	.9	1.9	1.3	1.3	380.9
600.	120.0	1.80	13.4	40.0	1.50	12.00	14.13	29.13	75.5	.942	6.3	417.1	4.6	1.2	1.6	1.7	1.5	373.0
600.	120.0	1.80	13.4	60.0	1.50	12.00	18.36	33.36	78.0	.935	6.4	423.1	4.9	1.0	1.8	1.7	1.5	377.2
600.	120.0	1.80	13.4	80.0	1.50	12.00	22.30	37.30	80.8	.931	6.4	426.9	5.1	.8	1.9	1.7	1.5	379.8
600.	120.0	1.40	13.4	40.0	2.50	12.00	14.23	29.23	75.5	.948	3.7	406.0	4.1	1.2	1.6	.7	.5	373.1
600.	120.0	1.40	13.4	60.0	2.50	12.00	18.49	33.49	78.0	.942	3.8	411.3	4.3	1.0	1.8	.7	.5	377.3
600.	120.0	1.40	13.4	80.0	2.50	12.00	22.47	37.47	80.8	.938	3.8	414.5	4.4	.9	1.9	.7	.5	379.9

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD
600.	120.0	1.50	13.4	40.0	2.50	12.00	14.20	29.20	75.5	.946	3.7	409.4	4.2	1.2	1.6	.8	.8	374.2
600.	120.0	1.50	13.4	60.0	2.50	12.00	18.45	33.45	78.0	.940	3.8	414.9	4.4	1.0	1.8	.8	.8	378.4
600.	120.0	1.50	13.4	80.0	2.50	12.00	22.42	37.42	80.8	.936	3.8	418.2	4.6	.9	1.9	.7	.8	381.0
600.	120.0	1.60	13.4	40.0	2.50	12.00	14.18	29.18	75.5	.945	3.7	412.3	4.3	1.2	1.6	1.0	1.0	374.8
600.	120.0	1.60	13.4	60.0	2.50	12.00	18.42	33.42	78.0	.938	3.8	417.9	4.5	1.0	1.8	1.0	1.0	379.0
600.	120.0	1.60	13.4	80.0	2.50	12.00	22.38	37.38	80.8	.934	3.8	421.4	4.7	.9	1.9	1.0	1.0	381.6
600.	120.0	1.70	13.4	40.0	2.50	12.00	14.16	29.16	75.5	.943	3.7	414.8	4.4	1.2	1.6	1.4	1.3	374.1
600.	120.0	1.70	13.4	60.0	2.50	12.00	18.39	33.39	78.0	.937	3.8	420.6	4.7	1.0	1.8	1.4	1.3	378.3
600.	120.0	1.70	13.4	80.0	2.50	12.00	22.34	37.34	80.8	.933	3.8	424.3	4.9	.9	1.9	1.3	1.3	380.9
600.	120.0	1.80	13.4	40.0	2.50	12.00	14.13	29.13	75.5	.942	3.8	417.1	4.6	1.2	1.6	1.7	1.5	373.0
600.	120.0	1.80	13.4	60.0	2.50	12.00	18.36	33.36	78.0	.935	3.8	423.1	4.9	1.0	1.8	1.7	1.5	377.2
600.	120.0	1.80	13.4	80.0	2.50	12.00	22.30	37.30	80.8	.931	3.8	426.9	5.1	.8	1.9	1.7	1.5	379.8
600.	120.0	1.40	13.4	40.0	5.00	12.00	14.23	29.23	75.5	.948	3.0	406.0	4.1	1.2	1.6	.7	.5	373.1
600.	120.0	1.40	13.4	60.0	5.00	12.00	18.49	33.49	78.0	.942	3.0	411.3	4.3	1.0	1.8	.7	.5	377.3
600.	120.0	1.40	13.4	80.0	5.00	12.00	22.47	37.47	80.8	.938	3.1	414.5	4.4	.9	1.9	.7	.5	379.9
600.	120.0	1.50	13.4	40.0	5.00	12.00	14.20	29.20	75.5	.946	2.9	409.4	4.2	1.2	1.6	.8	.8	374.2
600.	120.0	1.50	13.4	60.0	5.00	12.00	18.45	33.45	78.0	.940	3.0	414.9	4.4	1.0	1.8	.8	.8	378.4
600.	120.0	1.50	13.4	80.0	5.00	12.00	22.42	37.42	80.8	.936	3.0	418.2	4.6	.9	1.9	.7	.8	381.0
600.	120.0	1.60	13.4	40.0	5.00	12.00	14.18	29.18	75.5	.945	2.9	412.3	4.3	1.2	1.6	1.0	1.0	374.8
600.	120.0	1.60	13.4	60.0	5.00	12.00	18.42	33.42	78.0	.938	2.9	417.9	4.5	1.0	1.8	1.0	1.0	379.0
600.	120.0	1.60	13.4	80.0	5.00	12.00	22.38	37.38	80.8	.934	3.0	421.4	4.7	.9	1.9	1.0	1.0	381.6
600.	120.0	1.70	13.4	40.0	5.00	12.00	14.16	29.16	75.5	.943	2.8	414.8	4.4	1.2	1.6	1.4	1.3	374.1
600.	120.0	1.70	13.4	60.0	5.00	12.00	18.39	33.39	78.0	.937	2.9	420.6	4.7	1.0	1.8	1.4	1.3	378.3
600.	120.0	1.70	13.4	80.0	5.00	12.00	22.34	37.34	80.8	.933	2.9	424.3	4.9	.9	1.9	1.3	1.3	380.9
600.	120.0	1.80	13.4	40.0	5.00	12.00	14.13	29.13	75.5	.942	2.8	417.1	4.6	1.2	1.6	1.7	1.5	373.0
600.	120.0	1.80	13.4	60.0	5.00	12.00	18.36	33.36	78.0	.935	2.8	423.1	4.9	1.0	1.8	1.7	1.5	377.2
600.	120.0	1.80	13.4	80.0	5.00	12.00	22.30	37.30	80.8	.931	2.9	426.9	5.1	.8	1.9	1.7	1.5	379.8
600.	120.0	1.40	17.2	40.0	1.50	15.00	14.23	32.23	75.5	.948	6.2	406.0	4.1	1.2	1.6	1.0	.5	372.1
600.	120.0	1.40	17.2	60.0	1.50	15.00	18.49	36.49	78.0	.942	6.3	411.3	4.3	1.0	1.8	.9	.5	376.3
600.	120.0	1.40	17.2	80.0	1.50	15.00	22.47	40.47	80.8	.938	6.3	414.5	4.4	.9	1.9	.9	.5	378.9
600.	120.0	1.50	17.2	40.0	1.50	15.00	14.20	32.20	75.5	.946	6.2	409.4	4.2	1.2	1.6	1.1	.8	372.8
600.	120.0	1.50	17.2	60.0	1.50	15.00	18.45	36.45	78.0	.940	6.3	414.9	4.4	1.0	1.8	1.1	.8	377.0
600.	120.0	1.50	17.2	80.0	1.50	15.00	22.42	40.42	80.8	.936	6.3	418.2	4.6	.9	1.9	1.1	.8	379.6
600.	120.0	1.60	17.2	40.0	1.50	15.00	14.18	32.18	75.5	.945	6.2	412.3	4.3	1.2	1.6	1.5	1.0	372.8
600.	120.0	1.60	17.2	60.0	1.50	15.00	18.42	36.42	78.0	.938	6.3	417.9	4.5	1.0	1.8	1.5	1.0	377.0
600.	120.0	1.60	17.2	80.0	1.50	15.00	22.38	40.38	80.8	.934	6.4	421.4	4.7	.9	1.9	1.5	1.0	379.6
600.	120.0	1.70	17.2	40.0	1.50	15.00	14.16	32.16	75.5	.943	6.2	414.8	4.4	1.2	1.6	2.0	1.3	371.6
600.	120.0	1.70	17.2	60.0	1.50	15.00	18.39	36.39	78.0	.937	6.3	420.6	4.7	1.0	1.8	2.0	1.3	375.8
600.	120.0	1.70	17.2	80.0	1.50	15.00	22.34	40.34	80.8	.933	6.4	424.3	4.9	.8	1.9	2.0	1.3	378.4
600.	120.0	1.80	17.2	40.0	1.50	15.00	14.13	32.13	75.5	.942	6.3	417.1	4.6	1.1	1.6	2.5	1.5	370.0

239

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD
600.	120.0	1.80	17.2	60.0	1.50	15.00	18.36	36.36	78.0	.935	6.4	423.1	4.9	1.0	1.8	2.4	1.5	374.2
600.	120.0	1.80	17.2	80.0	1.50	15.00	22.30	40.30	80.8	.931	6.4	426.9	5.1	.8	1.9	2.5	1.5	376.7
600.	120.0	1.40	17.2	40.0	2.50	15.00	14.23	32.23	75.5	.948	3.7	406.0	4.1	1.2	1.6	1.0	.5	372.1
600.	120.0	1.40	17.2	60.0	2.50	15.00	18.49	36.49	78.0	.942	3.8	411.3	4.3	1.0	1.8	.9	.5	376.3
600.	120.0	1.40	17.2	80.0	2.50	15.00	22.47	40.47	80.8	.938	3.8	414.5	4.4	.9	1.9	.9	.5	378.9
600.	120.0	1.50	17.2	40.0	2.50	15.00	14.20	32.20	75.5	.946	3.7	409.4	4.2	1.2	1.6	1.1	.8	372.8
600.	120.0	1.50	17.2	60.0	2.50	15.00	18.45	36.45	78.0	.940	3.8	414.9	4.4	1.0	1.8	1.1	.8	377.0
600.	120.0	1.50	17.2	80.0	2.50	15.00	22.42	40.42	80.8	.936	3.8	418.2	4.6	.9	1.9	1.1	.8	379.6
600.	120.0	1.60	17.2	40.0	2.50	15.00	14.18	32.18	75.5	.945	3.7	412.3	4.3	1.2	1.6	1.5	1.0	372.8
600.	120.0	1.60	17.2	60.0	2.50	15.00	18.42	36.42	78.0	.938	3.8	417.9	4.5	1.0	1.8	1.5	1.0	377.0
600.	120.0	1.60	17.2	80.0	2.50	15.00	22.38	40.38	80.8	.934	3.8	421.4	4.7	.9	1.9	1.5	1.0	379.6
600.	120.0	1.70	17.2	40.0	2.50	15.00	14.16	32.16	75.5	.943	3.7	414.8	4.4	1.2	1.6	2.0	1.3	371.6
600.	120.0	1.70	17.2	60.0	2.50	15.00	18.39	36.39	78.0	.937	3.8	420.6	4.7	1.0	1.8	2.0	1.3	375.8
600.	120.0	1.70	17.2	80.0	2.50	15.00	22.34	40.34	80.8	.933	3.8	424.3	4.9	.8	1.9	2.0	1.3	378.4
600.	120.0	1.80	17.2	40.0	2.50	15.00	14.13	32.13	75.5	.942	3.8	417.1	4.6	1.1	1.6	2.5	1.5	370.0
600.	120.0	1.80	17.2	60.0	2.50	15.00	18.36	36.36	78.0	.935	3.8	423.1	4.9	1.0	1.8	2.4	1.5	374.2
600.	120.0	1.80	17.2	80.0	2.50	15.00	22.30	40.30	80.8	.931	3.8	426.9	5.1	.8	1.9	2.5	1.5	376.7
600.	120.0	1.40	17.2	40.0	5.00	15.00	14.23	32.23	75.5	.948	3.0	406.0	4.1	1.2	1.6	1.0	.5	372.1
600.	120.0	1.40	17.2	60.0	5.00	15.00	18.49	36.49	78.0	.942	3.0	411.3	4.3	1.0	1.8	.9	.5	376.3
600.	120.0	1.40	17.2	80.0	5.00	15.00	22.47	40.47	80.8	.938	3.1	414.5	4.4	.9	1.9	.9	.5	378.9
600.	120.0	1.50	17.2	40.0	5.00	15.00	14.20	32.20	75.5	.946	2.9	409.4	4.2	1.2	1.6	1.1	.8	372.8
600.	120.0	1.50	17.2	60.0	5.00	15.00	18.45	36.45	78.0	.940	3.0	414.9	4.4	1.0	1.8	1.1	.8	377.0
600.	120.0	1.50	17.2	80.0	5.00	15.00	22.42	40.42	80.8	.936	3.0	418.2	4.6	.9	1.9	1.1	.8	379.6
600.	120.0	1.60	17.2	40.0	5.00	15.00	14.18	32.18	75.5	.945	2.9	412.3	4.3	1.2	1.6	1.5	1.0	372.8
600.	120.0	1.60	17.2	60.0	5.00	15.00	18.42	36.42	78.0	.938	2.9	417.9	4.5	1.0	1.8	1.5	1.0	377.0
600.	120.0	1.60	17.2	80.0	5.00	15.00	22.38	40.38	80.8	.934	3.0	421.4	4.7	.9	1.9	1.5	1.0	379.6
600.	120.0	1.70	17.2	40.0	5.00	15.00	14.16	32.16	75.5	.943	2.8	414.8	4.4	1.2	1.6	2.0	1.3	371.6
600.	120.0	1.70	17.2	60.0	5.00	15.00	18.39	36.39	78.0	.937	2.9	420.6	4.7	1.0	1.8	2.0	1.3	375.8
600.	120.0	1.70	17.2	80.0	5.00	15.00	22.34	40.34	80.8	.933	2.9	424.3	4.9	.8	1.9	2.0	1.3	378.4
600.	120.0	1.80	17.2	40.0	5.00	15.00	14.13	32.13	75.5	.942	2.8	417.1	4.6	1.1	1.6	2.5	1.5	370.0
600.	120.0	1.80	17.2	60.0	5.00	15.00	18.36	36.36	78.0	.935	2.8	423.1	4.9	1.0	1.8	2.4	1.5	374.2
600.	120.0	1.80	17.2	80.0	5.00	15.00	22.30	40.30	80.8	.931	2.9	426.9	5.1	.8	1.9	2.5	1.5	376.7
600.	200.0	1.40	5.0	40.0	1.50	6.00	11.04	20.04	75.5	.736	10.3	406.7	3.2	1.2	1.6	.3	.5	379.5
600.	200.0	1.40	5.0	60.0	1.50	6.00	14.36	23.36	78.0	.731	10.4	411.8	3.3	1.0	1.7	.2	.5	383.9
600.	200.0	1.40	5.0	80.0	1.50	6.00	17.45	26.45	80.8	.728	10.5	415.0	3.4	.9	1.8	.2	.5	386.6
600.	200.0	1.50	5.0	40.0	1.50	6.00	11.02	20.02	75.5	.734	10.3	410.2	3.3	1.2	1.6	.3	.8	381.0
600.	200.0	1.50	5.0	60.0	1.50	6.00	14.33	23.33	78.0	.730	10.4	415.5	3.5	1.0	1.7	.3	.8	385.5
600.	200.0	1.50	5.0	80.0	1.50	6.00	17.41	26.41	80.8	.727	10.5	418.8	3.6	.9	1.8	.3	.8	388.2
600.	200.0	1.60	5.0	40.0	1.50	6.00	11.01	20.01	75.5	.733	10.3	413.1	3.4	1.2	1.6	.3	1.0	382.5
600.	200.0	1.60	5.0	60.0	1.50	6.00	14.30	23.30	78.0	.728	10.5	418.6	3.6	1.0	1.7	.3	1.0	387.0

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EFL	ISPD
600.	200.0	1.60	5.0	80.0	1.50	6.00	17.38	26.38	80.8	.725	10.6	422.0	3.7	.9	1.8	.3	1.0	389.8
600.	200.0	1.70	5.0	40.0	1.50	6.00	10.99	19.99	75.5	.732	10.4	415.7	3.5	1.2	1.5	.4	1.3	383.0
600.	200.0	1.70	5.0	60.0	1.50	6.00	14.28	23.28	78.0	.727	10.5	421.4	3.7	1.0	1.7	.3	1.3	387.6
600.	200.0	1.70	5.0	80.0	1.50	6.00	17.35	26.35	80.8	.724	10.6	424.9	3.8	.9	1.8	.3	1.3	390.4
600.	200.0	1.80	5.0	40.0	1.50	6.00	10.97	19.97	75.5	.731	10.4	418.1	3.6	1.2	1.5	.4	1.5	383.5
600.	200.0	1.80	5.0	60.0	1.50	6.00	14.25	23.25	78.0	.726	10.5	424.0	3.9	1.0	1.7	.4	1.5	388.1
600.	200.0	1.80	5.0	80.0	1.50	6.00	17.32	26.32	80.8	.723	10.6	427.6	4.0	.9	1.8	.4	1.5	390.9
600.	200.0	1.40	5.0	40.0	2.50	6.00	11.04	20.04	75.5	.736	6.2	406.7	3.2	1.2	1.6	.3	.5	379.5
600.	200.0	1.40	5.0	60.0	2.50	6.00	14.36	23.36	78.0	.731	6.2	411.8	3.3	1.0	1.7	.2	.5	383.9
600.	200.0	1.40	5.0	80.0	2.50	6.00	17.45	26.45	80.8	.728	6.3	415.0	3.4	.9	1.8	.2	.5	386.6
600.	200.0	1.50	5.0	40.0	2.50	6.00	11.02	20.02	75.5	.734	6.2	410.2	3.3	1.2	1.6	.3	.8	381.0
600.	200.0	1.50	5.0	60.0	2.50	6.00	14.33	23.33	78.0	.730	6.3	415.5	3.5	1.0	1.7	.3	.8	385.5
600.	200.0	1.50	5.0	80.0	2.50	6.00	17.41	26.41	80.8	.727	6.3	418.8	3.6	.9	1.8	.3	.8	388.2
600.	200.0	1.60	5.0	40.0	2.50	6.00	11.01	20.01	75.5	.733	6.2	413.1	3.4	1.2	1.6	.3	1.0	382.5
600.	200.0	1.60	5.0	60.0	2.50	6.00	14.30	23.30	78.0	.728	6.3	418.6	3.6	1.0	1.7	.3	1.0	387.0
600.	200.0	1.60	5.0	80.0	2.50	6.00	17.38	26.38	80.8	.725	6.3	422.0	3.7	.9	1.8	.3	1.0	389.8
600.	200.0	1.70	5.0	40.0	2.50	6.00	10.99	19.99	75.5	.732	6.2	415.7	3.5	1.2	1.5	.4	1.3	383.0
600.	200.0	1.70	5.0	60.0	2.50	6.00	14.28	23.28	78.0	.727	6.3	421.4	3.7	1.0	1.7	.3	1.3	387.6
600.	200.0	1.70	5.0	80.0	2.50	6.00	17.35	26.35	80.8	.724	6.4	424.9	3.8	.9	1.8	.3	1.3	390.4
600.	200.0	1.80	5.0	40.0	2.50	6.00	10.97	19.97	75.5	.731	6.2	418.1	3.6	1.2	1.5	.4	1.5	383.5
600.	200.0	1.80	5.0	60.0	2.50	6.00	14.25	23.25	78.0	.726	6.3	424.0	3.9	1.0	1.7	.4	1.5	388.1
600.	200.0	1.80	5.0	80.0	2.50	6.00	17.32	26.32	80.8	.723	6.4	427.6	4.0	.9	1.8	.4	1.5	390.9
600.	200.0	1.40	5.0	40.0	5.00	6.00	11.04	20.04	75.5	.736	3.9	406.7	3.2	1.2	1.6	.3	.5	379.5
600.	200.0	1.40	5.0	60.0	5.00	6.00	14.36	23.36	78.0	.731	3.9	411.8	3.3	1.0	1.7	.2	.5	383.9
600.	200.0	1.40	5.0	80.0	5.00	6.00	17.45	26.45	80.8	.728	4.0	415.0	3.4	.9	1.8	.2	.5	386.6
600.	200.0	1.50	5.0	40.0	5.00	6.00	11.02	20.02	75.5	.734	3.8	410.2	3.3	1.2	1.6	.3	.8	381.0
600.	200.0	1.50	5.0	60.0	5.00	6.00	14.33	23.33	78.0	.730	3.9	415.5	3.5	1.0	1.7	.3	.8	385.5
600.	200.0	1.50	5.0	80.0	5.00	6.00	17.41	26.41	80.8	.727	3.9	418.8	3.6	.9	1.8	.3	.8	388.2
600.	200.0	1.60	5.0	40.0	5.00	6.00	11.01	20.01	75.5	.733	3.7	413.1	3.4	1.2	1.6	.3	1.0	382.5
600.	200.0	1.60	5.0	60.0	5.00	6.00	14.30	23.30	78.0	.728	3.8	418.6	3.6	1.0	1.7	.3	1.0	387.0
600.	200.0	1.60	5.0	80.0	5.00	6.00	17.38	26.38	80.8	.725	3.8	422.0	3.7	.9	1.8	.3	1.0	389.8
600.	200.0	1.70	5.0	40.0	5.00	6.00	10.99	19.99	75.5	.732	3.7	415.7	3.5	1.2	1.5	.4	1.3	383.0
600.	200.0	1.70	5.0	60.0	5.00	6.00	14.28	23.28	78.0	.727	3.7	421.4	3.7	1.0	1.7	.3	1.3	387.6
600.	200.0	1.70	5.0	80.0	5.00	6.00	17.35	26.35	80.8	.724	3.8	424.9	3.8	.9	1.8	.3	1.3	390.4
600.	200.0	1.80	5.0	40.0	5.00	6.00	10.97	19.97	75.5	.731	3.6	418.1	3.6	1.2	1.5	.4	1.5	383.5
600.	200.0	1.80	5.0	60.0	5.00	6.00	14.25	23.25	78.0	.726	3.7	424.0	3.9	1.0	1.7	.4	1.5	388.1
600.	200.0	1.80	5.0	80.0	5.00	6.00	17.32	26.32	80.8	.723	3.7	427.6	4.0	.9	1.8	.4	1.5	390.9
600.	200.0	1.40	13.4	40.0	1.50	12.00	11.04	26.04	75.5	.736	10.3	406.7	3.2	1.2	1.6	.7	.5	377.6
600.	200.0	1.40	13.4	60.0	1.50	12.00	14.36	29.36	78.0	.731	10.4	411.8	3.3	1.0	1.7	.7	.5	382.1
600.	200.0	1.40	13.4	80.0	1.50	12.00	17.45	32.45	80.8	.728	10.5	415.0	3.4	.9	1.8	.7	.5	384.8

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD
600.	200.0	1.50	13.4	40.0	1.50	12.00	11.02	26.02	75.5	.734	10.3	410.2	3.3	1.2	1.6	.8	.8	378.8
600.	200.0	1.50	13.4	60.0	1.50	12.00	14.33	29.33	78.0	.730	10.4	415.5	3.5	1.0	1.7	.8	.8	383.3
600.	200.0	1.50	13.4	80.0	1.50	12.00	17.41	32.41	80.8	.727	10.5	418.8	3.6	.9	1.8	.8	.8	386.1
600.	200.0	1.60	13.4	40.0	1.50	12.00	11.01	26.01	75.5	.733	10.3	413.1	3.4	1.2	1.6	.9	1.0	379.8
600.	200.0	1.60	13.4	60.0	1.50	12.00	14.30	29.30	78.0	.728	10.5	418.6	3.6	1.0	1.7	.9	1.0	384.4
600.	200.0	1.60	13.4	80.0	1.50	12.00	17.38	32.38	80.8	.725	10.6	422.0	3.7	.9	1.8	.9	1.0	387.1
600.	200.0	1.70	13.4	40.0	1.50	12.00	10.99	25.99	75.5	.732	10.4	415.7	3.5	1.2	1.5	1.1	1.3	379.9
600.	200.0	1.70	13.4	60.0	1.50	12.00	14.28	29.28	78.0	.727	10.5	421.4	3.7	1.0	1.7	1.1	1.3	384.5
600.	200.0	1.70	13.4	80.0	1.50	12.00	17.35	32.35	80.8	.724	10.6	424.9	3.8	.9	1.8	1.1	1.3	387.3
600.	200.0	1.80	13.4	40.0	1.50	12.00	10.97	25.97	75.5	.731	10.4	418.1	3.6	1.2	1.5	1.3	1.5	379.7
600.	200.0	1.80	13.4	60.0	1.50	12.00	14.25	29.25	78.0	.726	10.5	424.0	3.9	1.0	1.7	1.3	1.5	384.4
600.	200.0	1.80	13.4	80.0	1.50	12.00	17.32	32.32	80.8	.723	10.6	427.6	4.0	.9	1.8	1.3	1.5	387.2
600.	200.0	1.40	13.4	40.0	2.50	12.00	11.04	26.04	75.5	.736	6.2	406.7	3.2	1.2	1.6	.7	.5	377.6
600.	200.0	1.40	13.4	60.0	2.50	12.00	14.36	29.36	78.0	.731	6.2	411.8	3.3	1.0	1.7	.7	.5	382.1
600.	200.0	1.40	13.4	80.0	2.50	12.00	17.45	32.45	80.8	.728	6.3	415.0	3.4	.9	1.8	.7	.5	384.8
600.	200.0	1.50	13.4	40.0	2.50	12.00	11.02	26.02	75.5	.734	6.2	410.2	3.3	1.2	1.6	.8	.8	378.8
600.	200.0	1.50	13.4	60.0	2.50	12.00	14.33	29.33	78.0	.730	6.3	415.5	3.5	1.0	1.7	.8	.8	383.3
600.	200.0	1.50	13.4	80.0	2.50	12.00	17.41	32.41	80.8	.727	6.3	418.8	3.6	.9	1.8	.8	.8	386.1
600.	200.0	1.60	13.4	40.0	2.50	12.00	11.01	26.01	75.5	.733	6.2	413.1	3.4	1.2	1.6	.9	1.0	379.8
600.	200.0	1.60	13.4	60.0	2.50	12.00	14.30	29.30	78.0	.728	6.3	418.6	3.6	1.0	1.7	.9	1.0	384.4
600.	200.0	1.60	13.4	80.0	2.50	12.00	17.38	32.38	80.8	.725	6.3	422.0	3.7	.9	1.8	.9	1.0	387.1
600.	200.0	1.70	13.4	40.0	2.50	12.00	10.99	25.99	75.5	.732	6.2	415.7	3.5	1.2	1.5	1.1	1.3	379.9
600.	200.0	1.70	13.4	60.0	2.50	12.00	14.28	29.28	78.0	.727	6.3	421.4	3.7	1.0	1.7	1.1	1.3	384.5
600.	200.0	1.70	13.4	80.0	2.50	12.00	17.35	32.35	80.8	.724	6.4	424.9	3.8	.9	1.8	1.1	1.3	387.3
600.	200.0	1.80	13.4	40.0	2.50	12.00	10.97	25.97	75.5	.731	6.2	418.1	3.6	1.2	1.5	1.3	1.5	379.7
600.	200.0	1.80	13.4	60.0	2.50	12.00	14.25	29.25	78.0	.726	6.3	424.0	3.9	1.0	1.7	1.3	1.5	384.4
600.	200.0	1.80	13.4	80.0	2.50	12.00	17.32	32.32	80.8	.723	6.4	427.6	4.0	.9	1.8	1.3	1.5	387.2
600.	200.0	1.40	13.4	40.0	5.00	12.00	11.04	26.04	75.5	.736	3.9	406.7	3.2	1.2	1.6	.7	.5	377.6
600.	200.0	1.40	13.4	60.0	5.00	12.00	14.36	29.36	78.0	.731	3.9	411.8	3.3	1.0	1.7	.7	.5	382.1
600.	200.0	1.40	13.4	80.0	5.00	12.00	17.45	32.45	80.8	.728	4.0	415.0	3.4	.9	1.8	.7	.5	384.8
600.	200.0	1.50	13.4	40.0	5.00	12.00	11.02	26.02	75.5	.734	3.8	410.2	3.3	1.2	1.6	.8	.8	378.8
600.	200.0	1.50	13.4	60.0	5.00	12.00	14.33	29.33	78.0	.730	3.9	415.5	3.5	1.0	1.7	.8	.8	383.3
600.	200.0	1.50	13.4	80.0	5.00	12.00	17.41	32.41	80.8	.727	3.9	418.8	3.6	.9	1.8	.8	.8	386.1
600.	200.0	1.60	13.4	40.0	5.00	12.00	11.01	26.01	75.5	.733	3.7	413.1	3.4	1.2	1.6	.9	1.0	379.8
600.	200.0	1.60	13.4	60.0	5.00	12.00	14.30	29.30	78.0	.728	3.8	418.6	3.6	1.0	1.7	.9	1.0	384.4
600.	200.0	1.60	13.4	80.0	5.00	12.00	17.38	32.38	80.8	.725	3.8	422.0	3.7	.9	1.8	.9	1.0	387.1
600.	200.0	1.70	13.4	40.0	5.00	12.00	10.99	25.99	75.5	.732	3.7	415.7	3.5	1.2	1.5	1.1	1.3	379.9
600.	200.0	1.70	13.4	60.0	5.00	12.00	14.28	29.28	78.0	.727	3.7	421.4	3.7	1.0	1.7	1.1	1.3	384.5
600.	200.0	1.70	13.4	80.0	5.00	12.00	17.35	32.35	80.8	.724	3.8	424.9	3.8	.9	1.8	1.1	1.3	387.3
600.	200.0	1.80	13.4	40.0	5.00	12.00	10.97	25.97	75.5	.731	3.6	418.1	3.6	1.2	1.5	1.3	1.5	379.7

ENGLISH UNITS - SEE NOMENCLATURE LIST

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD
600.	200.0	1.80	13.4	60.0	5.00	12.00	14.25	29.25	78.0	.726	3.7	424.0	3.9	1.0	1.7	1.3	1.5	384.4
600.	200.0	1.80	13.4	80.0	5.00	12.00	17.32	32.32	80.8	.723	3.7	427.6	4.0	.9	1.8	1.3	1.5	387.2
600.	200.0	1.40	17.2	40.0	1.50	15.00	11.04	29.04	75.5	.736	10.3	406.7	3.2	1.2	1.6	1.0	.5	376.6
600.	200.0	1.40	17.2	60.0	1.50	15.00	14.36	32.36	78.0	.731	10.4	411.8	3.3	1.0	1.7	.9	.5	381.1
600.	200.0	1.40	17.2	80.0	1.50	15.00	17.45	35.45	80.8	.728	10.5	415.0	3.4	.9	1.8	.9	.5	383.8
600.	200.0	1.50	17.2	40.0	1.50	15.00	11.02	29.02	75.5	.734	10.3	410.2	3.3	1.2	1.6	1.1	.8	377.5
600.	200.0	1.50	17.2	60.0	1.50	15.00	14.33	32.33	78.0	.730	10.4	415.5	3.5	1.0	1.7	1.1	.8	382.1
600.	200.0	1.50	17.2	80.0	1.50	15.00	17.41	35.41	80.8	.727	10.5	418.8	3.6	.9	1.8	1.1	.8	384.8
600.	200.0	1.60	17.2	40.0	1.50	15.00	11.01	29.01	75.5	.733	10.3	413.1	3.4	1.2	1.6	1.3	1.0	378.3
600.	200.0	1.60	17.2	60.0	1.50	15.00	14.30	32.30	78.0	.728	10.5	418.6	3.6	1.0	1.7	1.3	1.0	382.9
600.	200.0	1.60	17.2	80.0	1.50	15.00	17.38	35.38	80.8	.725	10.6	422.0	3.7	.9	1.8	1.3	1.0	385.7
600.	200.0	1.70	17.2	40.0	1.50	15.00	10.99	28.99	75.5	.732	10.4	415.7	3.5	1.2	1.5	1.6	1.3	378.0
600.	200.0	1.70	17.2	60.0	1.50	15.00	14.28	32.28	78.0	.727	10.5	421.4	3.7	1.0	1.7	1.5	1.3	382.7
600.	200.0	1.70	17.2	80.0	1.50	15.00	17.35	35.35	80.8	.724	10.6	424.9	3.8	.9	1.8	1.5	1.3	385.5
600.	200.0	1.80	17.2	40.0	1.50	15.00	10.97	28.97	75.5	.731	10.4	418.1	3.6	1.2	1.5	1.9	1.5	377.2
600.	200.0	1.80	17.2	60.0	1.50	15.00	14.25	32.25	78.0	.726	10.5	424.0	3.9	1.0	1.7	1.9	1.5	381.9
600.	200.0	1.80	17.2	80.0	1.50	15.00	17.32	35.32	80.8	.723	10.6	427.6	4.0	.9	1.8	1.9	1.5	384.7
600.	200.0	1.40	17.2	40.0	2.50	15.00	11.04	29.04	75.5	.736	6.2	406.7	3.2	1.2	1.6	1.0	.5	376.6
600.	200.0	1.40	17.2	60.0	2.50	15.00	14.36	32.36	78.0	.731	6.2	411.8	3.3	1.0	1.7	.9	.5	381.1
600.	200.0	1.40	17.2	80.0	2.50	15.00	17.45	35.45	80.8	.728	6.3	415.0	3.4	.9	1.8	.9	.5	383.8
600.	200.0	1.50	17.2	40.0	2.50	15.00	11.02	29.02	75.5	.734	6.2	410.2	3.3	1.2	1.6	1.1	.8	377.5
600.	200.0	1.50	17.2	60.0	2.50	15.00	14.33	32.33	78.0	.730	6.3	415.5	3.5	1.0	1.7	1.1	.8	382.1
600.	200.0	1.50	17.2	80.0	2.50	15.00	17.41	35.41	80.8	.727	6.3	418.8	3.6	.9	1.8	1.1	.8	384.8
600.	200.0	1.60	17.2	40.0	2.50	15.00	11.01	29.01	75.5	.733	6.2	413.1	3.4	1.2	1.6	1.3	1.0	378.3
600.	200.0	1.60	17.2	60.0	2.50	15.00	14.30	32.30	78.0	.728	6.3	418.6	3.6	1.0	1.7	1.3	1.0	382.9
600.	200.0	1.60	17.2	80.0	2.50	15.00	17.38	35.38	80.8	.725	6.3	422.0	3.7	.9	1.8	1.3	1.0	385.7
600.	200.0	1.70	17.2	40.0	2.50	15.00	10.99	28.99	75.5	.732	6.2	415.7	3.5	1.2	1.5	1.6	1.3	378.0
600.	200.0	1.70	17.2	60.0	2.50	15.00	14.28	32.28	78.0	.727	6.3	421.4	3.7	1.0	1.7	1.5	1.3	382.7
600.	200.0	1.70	17.2	80.0	2.50	15.00	17.35	35.35	80.8	.724	6.4	424.9	3.8	.9	1.8	1.5	1.3	385.5
600.	200.0	1.80	17.2	40.0	2.50	15.00	10.97	28.97	75.5	.731	6.2	418.1	3.6	1.2	1.5	1.9	1.5	377.2
600.	200.0	1.80	17.2	60.0	2.50	15.00	14.25	32.25	78.0	.726	6.3	424.0	3.9	1.0	1.7	1.9	1.5	381.9
600.	200.0	1.80	17.2	80.0	2.50	15.00	17.32	35.32	80.8	.723	6.4	427.6	4.0	.9	1.8	1.9	1.5	384.7
600.	200.0	1.40	17.2	40.0	5.00	15.00	11.04	29.04	75.5	.736	3.9	406.7	3.2	1.2	1.6	1.0	.5	376.6
600.	200.0	1.40	17.2	60.0	5.00	15.00	14.36	32.36	78.0	.731	3.9	411.8	3.3	1.0	1.7	.9	.5	381.1
600.	200.0	1.40	17.2	80.0	5.00	15.00	17.45	35.45	80.8	.728	4.0	415.0	3.4	.9	1.8	.9	.5	383.8
600.	200.0	1.50	17.2	40.0	5.00	15.00	11.02	29.02	75.5	.734	3.8	410.2	3.3	1.2	1.6	1.1	.8	377.5
600.	200.0	1.50	17.2	60.0	5.00	15.00	14.33	32.33	78.0	.730	3.9	415.5	3.5	1.0	1.7	1.1	.8	382.1
600.	200.0	1.50	17.2	80.0	5.00	15.00	17.41	35.41	80.8	.727	3.9	418.8	3.6	.9	1.8	1.1	.8	384.8
600.	200.0	1.60	17.2	40.0	5.00	15.00	11.01	29.01	75.5	.733	3.7	413.1	3.4	1.2	1.6	1.3	1.0	378.3
600.	200.0	1.60	17.2	60.0	5.00	15.00	14.30	32.30	78.0	.728	3.8	418.6	3.6	1.0	1.7	1.3	1.0	382.9

THRUST	PC	O/F	%FFC	EPS	CR	LPRIME	LNOZ	LENG	%BELL	RSTAR	F/E	ISPT	%KL	%DL	%BLL	%FCL	%EPL	ISPD
ENGLISH UNITS - SEE NOMENCLATURE LIST																		
600.	200.0	1.60	17.2	80.0	5.00	15.00	17.38	35.38	80.8	.725	3.8	422.0	3.7	.9	1.8	1.3	1.0	385.7
600.	200.0	1.70	17.2	40.0	5.00	15.00	10.99	28.99	75.5	.732	3.7	415.7	3.5	1.2	1.5	1.6	1.3	378.0
600.	200.0	1.70	17.2	60.0	5.00	15.00	14.28	32.28	78.0	.727	3.7	421.4	3.7	1.0	1.7	1.5	1.3	382.7
600.	200.0	1.70	17.2	80.0	5.00	15.00	17.35	35.35	80.8	.724	3.8	424.9	3.8	.9	1.8	1.5	1.3	385.5
600.	200.0	1.80	17.2	40.0	5.00	15.00	10.97	28.97	75.5	.731	3.6	418.1	3.6	1.2	1.5	1.9	1.5	377.2
600.	200.0	1.80	17.2	60.0	5.00	15.00	14.25	32.25	78.0	.726	3.7	424.0	3.9	1.0	1.7	1.9	1.5	381.9
600.	200.0	1.80	17.2	80.0	5.00	15.00	17.32	35.32	80.8	.723	3.7	427.6	4.0	.9	1.8	1.9	1.5	384.7

APPENDIX B

WEIGHT EVALUATION DATA

APPENDIX B

TABLE SET A

LIQUID-LIQUID ENGINE WEIGHT TABULATION

LIQUID-LIQUID ENGINE
800 SECONDS

P_c	CR	L'	Ae/At	Injector	Comb. Chbr.	Nozzle	Weight-lb Gimb. Ring	Gimb. Supt.	Noz. Clamp	Insulation	Total
80	1.5	6	40	2.9	16.0	3.7	1.5	0.7	0.6	2.1	27.5
			60	2.9	16.0	5.6	1.5	0.7	0.6	2.1	29.4
			80	2.9	16.0	7.7	1.5	0.7	0.6	2.1	31.5
		12	40	2.9	26.1	3.7	1.5	1.1	0.6	3.7	39.6
			60	2.9	26.1	5.6	1.5	1.1	0.6	3.7	41.5
			80	2.9	26.1	7.7	1.5	1.1	0.6	3.7	43.6
		15	40	2.9	31.1	3.7	1.5	1.3	0.6	4.5	45.6
			60	2.9	31.1	5.6	1.5	1.3	0.6	4.5	47.5
			80	2.9	31.1	7.7	1.5	1.3	0.6	4.5	49.6
	2.25	6	40	3.9	17.8	3.7	1.5	0.7	0.6	2.2	30.4
			60	3.9	17.8	5.6	1.5	0.7	0.6	2.2	32.3
			80	3.9	17.8	7.7	1.5	0.7	0.6	2.2	34.4
		12	40	3.9	29.2	3.7	1.5	1.2	0.6	3.8	43.9
			60	3.9	29.2	5.6	1.5	1.2	0.6	3.8	45.8
			80	3.9	29.2	7.7	1.5	1.2	0.6	3.8	47.9
		15	40	3.9	34.9	3.7	1.5	1.4	0.6	4.7	50.7
			60	3.9	34.9	5.6	1.5	1.4	0.6	4.7	52.6
			80	3.9	34.9	7.7	1.5	1.4	0.6	4.7	54.7
	5.0	6	40	7.3	23.0	3.7	1.5	0.8	0.6	2.4	39.3
			60	7.3	23.0	5.6	1.5	0.8	0.6	2.4	41.2
			80	7.3	23.0	7.7	1.5	0.8	0.6	2.4	43.3
		12	40	7.3	38.4	3.7	1.5	1.3	0.6	4.2	57.0
			60	7.3	38.4	5.6	1.5	1.3	0.6	4.2	58.9
			80	7.3	38.4	7.7	1.5	1.3	0.6	4.2	61.0
		15	40	7.3	46.0	3.7	1.5	1.6	0.6	5.1	65.8
			60	7.3	46.0	5.6	1.5	1.6	0.6	5.1	67.7
			80	7.3	46.0	7.7	1.5	1.6	0.6	5.1	69.8

Appendix B, Table Set A

LIQUID-LIQUID ENGINE
800 SECONDS

P_c	CR	L'	Ae/At	Weight-lb Injector	Comb. Chbr.	Nozzle	Gimb. Ring	Gimb. Supt.	Noz. Clamp	Insulation	Total
120	1.5	6	40	2.2	13.2	2.5	1.5	0.6	0.6	2.0	22.6
			60	2.2	13.2	3.8	1.5	0.6	0.6	2.0	23.9
			80	2.2	13.2	5.2	1.5	0.6	0.6	2.0	25.3
		12	40	2.2	21.5	2.5	1.5	1.1	0.6	3.5	32.9
			60	2.2	21.5	3.8	1.5	1.1	0.6	3.5	34.2
			80	2.2	21.5	5.2	1.5	1.1	0.6	3.5	35.6
		15	40	2.2	25.6	2.5	1.5	1.3	0.6	4.3	38.0
			60	2.2	25.6	3.8	1.5	1.3	0.6	4.3	39.3
			80	2.2	25.6	5.2	1.5	1.3	0.6	4.3	40.7
	2.25	6	40	2.9	14.5	2.5	1.5	0.7	0.6	2.1	24.8
			60	2.9	14.5	3.8	1.5	0.7	0.6	2.1	26.1
			80	2.9	14.5	5.2	1.5	0.7	0.6	2.1	27.5
		12	40	2.9	23.8	2.5	1.5	1.1	0.6	3.6	36.0
			60	2.9	23.8	3.8	1.5	1.1	0.6	3.6	37.3
			80	2.9	23.8	5.2	1.5	1.1	0.6	3.6	38.7
		15	40	2.9	28.4	2.5	1.5	1.3	0.6	4.4	41.6
			60	2.9	28.4	3.8	1.5	1.3	0.6	4.4	42.9
			80	2.9	28.4	5.2	1.5	1.3	0.6	4.4	44.3
	5.0	6	40	5.3	18.3	2.5	1.5	0.8	0.6	2.2	31.2
			60	5.3	18.3	3.8	1.5	0.8	0.6	2.2	32.5
			80	5.3	18.3	5.2	1.5	0.8	0.6	2.2	33.9
		12	40	5.3	30.5	2.5	1.5	1.2	0.6	3.9	45.5
			60	5.3	30.5	3.8	1.5	1.2	0.6	3.9	46.8
			80	5.3	30.5	5.2	1.5	1.2	0.6	3.9	48.2
		15	40	5.3	36.5	2.5	1.5	1.5	0.6	4.7	52.6
			60	5.3	36.5	3.8	1.5	1.5	0.6	4.7	53.9
			80	5.3	36.5	5.2	1.5	1.5	0.6	4.7	55.3

249

LIQUID-LIQUID ENGINE
800 SECONDS

				Weight-lb							
P_c	CR	L'	Ae/At	Injector	Comb. Chbr.	Nozzle	Gimb. Ring	Gimb. Supt.	Noz. Clamp	Insulation	Total
200	1.5	6	40	1.6	11.9	1.6	1.5	0.6	0.5	1.9	19.6
			60	1.6	11.9	2.4	1.5	0.6	0.5	1.9	20.4
			80	1.6	11.9	3.2	1.5	0.6	0.5	1.9	21.2
		12	40	1.6	18.6	1.6	1.5	1.0	0.5	3.3	28.1
			60	1.6	18.6	2.4	1.5	1.0	0.5	3.3	28.9
			80	1.6	18.6	3.2	1.5	1.0	0.5	3.3	29.7
		15	40	1.6	21.9	1.6	1.5	1.2	0.5	4.1	32.4
			60	1.6	21.9	2.4	1.5	1.2	0.5	4.1	33.2
			80	1.6	21.9	3.2	1.5	1.2	0.5	4.1	34.0
	2.25	6	40	2.1	12.8	1.6	1.5	0.6	0.5	2.0	21.1
			60	2.1	12.8	2.4	1.5	0.6	0.5	2.0	21.9
			80	2.1	12.8	3.2	1.5	0.6	0.5	2.0	22.7
		12	40	2.1	20.1	1.6	1.5	1.1	0.5	3.4	30.3
			60	2.1	20.1	2.4	1.5	1.1	0.5	3.4	31.1
			80	2.1	20.1	3.2	1.5	1.1	0.5	3.4	31.9
		15	40	2.1	23.8	1.6	1.5	1.3	0.5	4.1	34.9
			60	2.1	23.8	2.4	1.5	1.3	0.5	4.1	35.7
			80	2.1	23.8	3.2	1.5	1.3	0.5	4.1	36.5
	5.0	6	40	3.6	15.4	1.6	1.5	0.7	0.5	2.1	25.4
			60	3.6	15.4	2.4	1.5	0.7	0.5	2.1	26.2
			80	3.6	15.4	3.2	1.5	0.7	0.5	2.1	27.0
		12	40	3.6	24.7	1.6	1.5	1.2	0.5	3.6	36.7
			60	3.6	24.7	2.4	1.5	1.2	0.5	3.6	37.5
			80	3.6	24.7	3.2	1.5	1.2	0.5	3.6	38.3
		15	40	3.6	29.3	1.6	1.5	1.4	0.5	4.4	42.3
			60	3.6	29.3	2.4	1.5	1.4	0.5	4.4	43.1
			80	3.6	29.3	3.2	1.5	1.4	0.5	4.4	43.9

LIQUID-LIQUID ENGINE
2000 SECONDS

P_c	CR	L'	Ae/At	Weight-lb Injector	Comb. Chbr.	Nozzle	Gimb. Ring	Gimb. Supt.	Noz. Clamp	Insulation	Total
80	1.5	6	40	3.3	22.8	3.8	1.5	0.7	0.7	2.3	35.1
			60	3.3	22.8	5.7	1.5	0.7	0.7	2.3	37.0
			80	3.3	22.8	7.8	1.5	0.7	0.7	2.3	39.1
		12	40	3.3	36.6	3.8	1.5	1.2	0.7	4.0	51.1
			60	3.3	36.6	5.7	1.5	1.2	0.7	4.0	53.0
			80	3.3	36.6	7.8	1.5	1.2	0.7	4.0	55.1
		15	40	3.3	43.5	3.8	1.5	1.4	0.7	4.8	59.0
			60	3.3	43.5	5.7	1.5	1.4	0.7	4.8	60.9
			80	3.3	43.5	7.8	1.5	1.4	0.7	4.8	63.0
	2.25	6	40	4.3	24.9	3.8	1.5	0.8	0.7	2.4	38.4
			60	4.3	24.9	5.7	1.5	0.8	0.7	2.4	40.3
			80	4.3	24.9	7.8	1.5	0.8	0.7	2.4	42.4
		12	40	4.3	40.3	3.8	1.5	1,2	0.7	4.1	55.9
			60	4.3	40.3	5.7	1.5	1.2	0.7	4.1	57.8
			80	4.3	40.3	7.8	1.5	1.2	0.7	4.1	59.9
		15	40	4.3	48.1	3.8	1.5	1.5	0.7	5.0	64.9
			60	4.3	48.1	5.7	1.5	1.5	0.7	5.0	66.8
			80	4.3	48.1	7.8	1.5	1.5	0.7	5.0	68.9
	5.0	6	40	7.7	31.3	3.8	1.5	0.9	0.7	2.5	48.4
			60	7.7	31.3	5.7	1.5	0.9	0.7	2.5	50.3
			80	7.7	31.3	7.8	1.5	0.9	0.7	2.5	52.4
		12	40	7.7	51.4	3.8	1.5	1.4	0.7	4.4	70.9
			60	7.7	51.4	5.7	1.5	1.4	0.7	4.4	72.8
			80	7.7	51.4	7.8	1.5	1.4	0.7	4.4	74.9
		15	40	7.7	61.5	3.8	1.5	1.7	0.7	5.4	82.3
			60	7.7	61.5	5.7	1.5	1.7	0.7	5.4	84.2
			80	7.7	61.5	7.8	1.5	1.7	0.7	5.4	86.3

Appendix B, Table Set A

LIQUID-LIQUID ENGINE
2000 SECONDS

P_c	CR	L'	Ae/At	Injector	Comb. Chbr.	Nozzle	Weight-lb Gimb. Ring	Gimb. Supt.	Noz. Clamp	Insulation	Total
120	1.5	6	40	2.6	19.2	2.6	1.5	0.7	0.6	2.2	29.4
			60	2.6	19.2	3.9	1.5	0.7	0.6	2.2	30.7
			80	2.6	19.2	5.3	1.5	0.7	0.6	2.2	32.1
		12	40	2.6	30.8	2.6	1.5	1.1	0.6	3.8	43.0
			60	2.6	30.8	3.9	1.5	1.1	0.6	3.8	44.3
			80	2.6	30.8	5.3	1.5	1.1	0.6	3.8	45.7
		15	40	2.6	36.6	2.6	1.5	1.4	0.6	4.6	49.9
			60	2.6	36.6	3.9	1.5	1.4	0.6	4.6	51.2
			80	2.6	36.6	5.3	1.5	1.4	0.6	4.6	52.6
	2.25	6	40	3.3	20.8	2.6	1.5	0.7	0.6	2.2	31.7
			60	3.3	20.8	3.9	1.5	0.7	0.6	2.2	33.0
			80	3.3	20.8	5.3	1.5	0.7	0.6	2.2	34.4
		12	40	3.3	33.6	2.6	1.5	1.2	0.6	3.9	46.7
			60	3.3	33.6	3.9	1.5	1.2	0.6	3.9	48.0
			80	3.3	33.6	5.3	1.5	1.2	0.6	3.9	49.4
		15	40	3.3	40.0	2.6	1.5	1.4	0.6	4.7	54.1
			60	3.3	40.0	3.9	1.5	1.4	0.6	4.7	55.4
			80	3.3	40.0	5.3	1.5	1.4	0.6	4.7	56.8
	5.0	6	40	5.7	25.5	2.6	1.5	0.8	0.6	2.4	39.1
			60	5.7	25.5	3.9	1.5	0.8	0.6	2.4	40.4
			80	5.7	25.5	5.3	1.5	0.8	0.6	2.4	41.8
		12	40	5.7	41.8	2.6	1.5	1.3	0.6	4.2	57.7
			60	5.7	41.8	3.9	1.5	1.3	0.6	4.2	59.0
			80	5.7	41.8	5.3	1.5	1.3	0.6	4.2	60.4
		15	40	5.7	49.9	2.6	1.5	1.6	0.6	5.1	67.0
			60	5.7	49.9	3.9	1.5	1.6	0.6	5.1	68.3
			80	5.7	59.9	5.3	1.5	1.6	0.6	5.1	69.7

LIQUID-LIQUID ENGINE
2000 SECONDS

P_c	CR	L'	Ae/At	Injector	Comb. Chbr.	Nozzle	Weight-lb Gimb. Ring	Gimb. Supt.	Noz. Clamp	Insulation	Total
200	1.5	6	40	1.9	16.0	1.7	1.5	0.7	0.6	2.1	24.5
			60	1.9	16.0	2.5	1.5	0.7	0.6	2.1	25.3
			80	1.9	16.0	3.3	1.5	0.7	0.6	2.1	26.1
		12	40	1.9	25.6	1.7	1.5	1.1	0.6	3.6	36.0
			60	1.9	25.6	2.5	1.5	1.1	0.6	3.6	36.8
			80	1.9	25.6	3.3	1.5	1.1	0.6	3.6	37.6
		15	40	1.9	30.4	1.7	1.5	1.3	0.6	4.4	41.8
			60	1.9	30.4	2.5	1.5	1.3	0.1	4.4	42.6
			80	1.9	30.4	3.3	1.5	1.3	0.6	4.4	43.4
	2.25	6	40	2.4	17.1	1.7	1.5	0.7	0.6	2.1	26.1
			60	2.4	17.1	2.5	1.5	0.7	0.6	2.1	26.9
			80	2.4	17.1	3.3	1.5	0.7	0.6	2.1	27.7
		12	40	2.4	27.6	1.7	1.5	1.1	0.6	3.7	38.6
			60	2.4	27.6	2.5	1.5	1.1	0.6	3.7	39.4
			80	2.4	27.6	3.3	1.5	1.1	0.6	3.7	40.2
		15	40	2.4	32.8	1.7	1.5	1.4	0.6	4.5	44.9
			60	2.4	32.8	2.5	1.5	1.4	0.6	4.5	45.7
			80	2.4	32.8	3.3	1.5	1.4	0.6	4.5	46.5
	5.0	6	40	4.0	20.3	1.7	1.5	0.8	0.6	2.2	31.1
			60	4.0	20.3	2.5	1.5	0.8	0.6	2.2	31.9
			80	4.0	20.3	3.3	1.5	0.8	0.6	2.2	32.7
		12	40	4.0	33.2	1.7	1.5	1.2	0.6	3.9	46.1
			60	4.0	33.2	2.5	1.5	1.2	0.6	3.9	46.9
			80	4.0	33.2	3.3	1.5	1.2	0.6	3.9	47.7
		15	40	4.0	39.6	1.7	1.5	1.5	0.6	4.7	53.6
			60	4.0	39.6	2.5	1.5	1.5	0.6	4.7	54.4
			80	4.0	39.6	3.3	1.5	1.5	0.6	4.7	55.2

APPENDIX B

TABLE SET B

BIMODAL ENGINE WEIGHT TABULATION

BI-MODE ENGINE
800 SECONDS

P_c	CR	L'	Ae/At	Injector	Comb. Chbr.	Nozzle	Weight-lb Gimb. Ring	Gimb. Supt.	Noz. Clamp	Insulation	Total
80	1.5	6	40	6.7	14.7	3.7	1.5	0.6	0.6	2.1	29.9
			60	6.7	14.7	5.6	1.5	0.6	0.6	2.1	31.8
			80	6.7	14.7	7.7	1.5	0.6	0.6	2.1	33.9
		12	40	6.7	24.8	3.7	1.5	1.0	0.6	3.7	42.0
			60	6.7	24.8	5.6	1.5	1.0	0.6	3.7	43.9
			80	6.7	24.8	7.7	1.5	1.0	0.6	3.7	46.0
		15	40	6.7	29.9	3.7	1.5	1.3	0.6	4.5	48.2
			60	6.7	29.9	5.6	1.5	1.3	0.6	4.5	50.1
			80	6.7	29.9	7.7	1.5	1.3	0.6	4.5	52.2
	2.50	6	40	8.6	16.4	3.7	1.5	0.7	0.6	2.2	33.7
			60	8.6	16.4	5.6	1.5	0.7	0.6	2.2	35.6
			80	8.6	16.4	7.7	1.5	0.7	0.6	2.2	37.7
		12	40	8.6	27.9	3.7	1.5	1.1	0.6	3.8	47.2
			60	8.6	27.9	5.6	1.5	1.1	0.6	3.8	49.1
			80	8.6	27.9	7.7	1.5	1.1	0.6	3.8	51.2
		15	40	8.6	43.1	3.7	1.5	1.3	0.6	4.7	63.5
			60	8.6	43.1	5.6	1.5	1.3	0.6	4.7	65.4
			80	8.6	43.1	7.7	1.5	1.3	0.6	4.7	67.5
	5.0	6	40	14.9	21.6	3.7	1.5	0.7	0.6	2.4	45.4
			60	14.9	21.6	5.6	1.5	0.7	0.6	2.4	47.3
			80	14.9	21.6	7.7	1.5	0.7	0.6	2.4	49.4
		12	40	14.9	36.9	3.7	1.5	1.3	0.6	4.2	63.1
			60	14.9	36.9	5.6	1.5	1.3	0.6	4.2	65.0
			80	14.9	36.9	7.7	1.5	1.3	0.6	4.2	67.1
		15	40	14.9	44.6	3.7	1.5	1.5	0.6	5.1	71.9
			60	14.9	44.6	5.6	1.5	1.5	0.6	5.1	73.8
			80	14.9	44.6	7.7	1.5	1.5	0.6	5.1	75.9

Appendix B, Table Set B

BI-MODE ENGINE
800 SECONDS

P_c	CR	L'	Ae/At	Weight-lb Injector	Comb. Chbr.	Nozzle	Gimb. Ring	Gimb. Supt.	Noz. Clamp	Insulation	Total
120	1.5	6	40	5.3	12.2	2.5	1.5	0.6	0.6	2.0	24.7
			60	5.3	12.2	3.8	1.5	0.6	0.6	2.0	26.0
			80	5.3	12.2	5.2	1.5	0.6	0.6	2.0	27.4
		12	40	5.3	20.5	2.5	1.5	1.0	0.6	3.5	34.9
			60	5.3	20.5	3.8	1.5	1.0	0.6	3.5	36.2
			80	5.3	20.5	5.2	1.5	1.0	0.6	3.5	37.6
		15	40	5.3	24.6	2.5	1.5	1.2	0.6	4.3	40.0
			60	5.3	24.6	3.8	1.5	1.2	0.6	4.3	41.3
			80	5.3	24.6	5.2	1.5	1.2	0.6	4.3	42.7
	2.50	6	40	6.7	13.4	2.5	1.5	0.6	0.6	2.1	27.4
			60	6.7	13.4	3.8	1.5	0.6	0.6	2.1	28.7
			80	6.7	13.4	5.2	1.5	0.6	0.6	2.1	30.1
		12	40	6.7	22.7	2.5	1.5	1.0	0.6	3.6	38.6
			60	6.7	22.7	3.8	1.5	1.0	0.6	3.6	39.9
			80	6.7	22.7	5.2	1.5	1.0	0.6	3.6	41.3
		15	40	6.7	27.3	2.5	1.5	1.3	0.6	4.4	44.3
			60	6.7	27.3	3.8	1.5	1.3	0.6	4.4	45.6
			80	6.7	27.3	5.2	1.5	1.3	0.6	4.4	47.0
	5.0	6	40	11.2	17.2	2.5	1.5	0.7	0.6	2.2	35.9
			60	11.2	17.2	3.8	1.5	0.7	0.6	2.2	37.2
			80	11.2	17.2	5.2	1.5	0.7	0.6	2.2	38.6
		12	40	11.2	29.3	2.5	1.5	1.2	0.6	3.9	50.2
			60	11.2	29.3	3.8	1.5	1.2	0.6	3.9	51.5
			80	11.2	29.3	5.2	1.5	1.2	0.6	3.9	52.9
		15	40	11.2	35.4	2.5	1.5	1.4	0.6	4.7	57.3
			60	11.2	35.4	3.8	1.5	1.4	0.6	4.7	58.6
			80	11.2	35.4	5.2	1.5	1.4	0.6	4.7	60.0

255

BI-MODE ENGINE
800 SECONDS

P_c	CR	L'	Ae/At	Injector	Comb. Chbr.	Nozzle	Weight-lb Gimb. Ring	Gimb. Supt.	Noz. Clamp	Insulation	Total
200	1.5	6	40	4.1	9.9	1.6	1.5	0.5	0.5	1.9	20.0
			60	4.1	9.9	2.4	1.5	0.5	0.5	1.9	20.8
			80	4.1	9.9	3.2	1.5	0.5	0.5	1.9	21.6
		12	40	4.1	16.6	1.6	1.5	1.0	0.5	3.3	28.6
			60	4.1	16.6	2.4	1.5	1.0	0.5	3.3	29.4
			80	4.1	16.6	3.2	1.5	1.0	0.5	3.3	30.2
		15	40	4.1	19.9	1.6	1.5	1.2	0.5	4.1	32.9
			60	4.1	19.9	2.4	1.5	1.2	0.5	4.1	33.7
			80	4.1	19.9	3.2	1.5	1.2	0.5	4.1	34.5
	2.50	6	40	5.1	10.7	1.6	1.5	0.6	0.5	2.0	22.0
			60	5.1	10.7	2.4	1.5	0.6	0.5	2.0	22.8
			80	5.1	10.7	3.2	1.5	0.6	0.5	2.0	23.6
		12	40	5.1	18.1	1.6	1.5	1.0	0.5	3.4	31.2
			60	5.1	18.1	2.4	1.5	1.0	0.5	3.4	32.0
			80	5.1	18.1	3.2	1.5	1.0	0.5	3.4	32.8
		15	40	5.1	21.8	1.6	1.5	1.2	0.5	4.1	35.8
			60	5.1	21.8	2.4	1.5	1.2	0.5	4.1	36.6
			80	5.1	21.8	3.2	1.5	1.2	0.5	4.1	37.4
	5.0	6	40	8.0	13.3	1.6	1.5	0.6	0.5	2.1	27.6
			60	8.0	13.3	2.4	1.5	0.6	0.5	2.1	28.4
			80	8.0	13.3	3.2	1.5	0.6	0.5	2.1	29.2
		12	40	8.0	15.3	1.6	1.5	1.1	0.5	3.6	31.6
			60	8.0	15.3	2.4	1.5	1.1	0.5	3.6	32.4
			80	8.0	15.3	3.2	1.5	1.1	0.5	3.6	33.2
		15	40	8.0	27.3	1.6	1.5	1.3	0.5	4.4	44.6
			60	8.0	27.3	2.4	1.5	1.3	0.5	4.4	45.4
			80	8.0	27.3	3.2	1.5	1.3	0.5	4.4	46.2

BI-MODE ENGINE
2000 SECONDS

P_c	CR	L'	Ae/At	Weight-lb Injector	Comb. Chbr.	Nozzle	Gimb. Ring	Gimb. Supt.	Noz. Clamp	Insulation	Total
80	1.5	6	40	7.1	21.8	3.8	1.5	0.7	0.7	2.3	37.9
			60	7.1	21.8	5.7	1.5	0.7	0.7	2.3	39.8
			80	7.1	21.8	7.8	1.5	0.7	0.7	2.3	41.9
		12	40	7.1	35.8	3.8	1.5	1.1	0.7	4.0	54.0
			60	7.1	35.8	5.7	1.5	1.1	0.7	4.0	55.9
			80	7.1	35.8	7.8	1.5	1.1	0.7	4.0	58.0
		15	40	7.1	42.9	3.8	1.5	1.4	0.7	4.8	62.2
			60	7.1	42.9	5.7	1.5	1.4	0.7	4.8	64.1
			80	7.1	42.9	7.8	1.5	1.4	0.7	4.8	66.2
	2.50	6	40	9.0	23.8	3.8	1.5	0.7	0.7	2.4	41.9
			60	9.0	23.8	5.7	1.5	0.7	0.7	2.4	43.8
			80	9.0	23.8	7.8	1.5	0.7	0.7	2.4	45.9
		12	40	9.0	39.5	3.8	1.5	1.2	0.7	4.1	59.8
			60	9.0	39.5	5.7	1.5	1.2	0.7	4.1	61.7
			80	9.0	39.5	7.8	1.5	1.2	0.7	4.1	63.8
		15	40	9.0	47.4	3.8	1.5	1.4	0.7	5.0	68.8
			60	9.0	47.4	5.7	1.5	1.4	0.7	5.0	70.7
			80	9.0	47.4	7.8	1.5	1.4	0.7	5.0	72.8
	5.0	6	40	15.2	29.9	3.8	1.5	0.8	0.7	2.5	54.4
			60	15.2	29.9	5.7	1.5	0.8	0.7	2.5	56.3
			80	15.2	29.9	7.8	1.5	0.8	0.7	2.5	58.4
		12	40	15.2	50.4	3.8	1.5	1.3	0.7	4.4	77.3
			60	15.2	50.4	5.7	1.5	1.3	0.7	4.4	79.2
			80	15.2	50.4	7.8	1.5	1.3	0.7	4.4	81.3
		15	40	15.2	60.6	3.8	1.5	1.6	0.7	5.4	88.8
			60	15.2	60.6	5.7	1.5	1.6	0.7	5.4	90.7
			80	15.2	60.6	7.8	1.5	1.6	0.7	5.4	92.8

Appendix B, Table Set B

257

BI-MODE ENGINE
2000 SECONDS

P_c	CR	L'	Ae/At	Weight-lb Injector	Comb. Chbr.	Nozzle	Gimb. Ring	Gimb. Supt.	Noz. Clamp	Insulation	Total
120	1.5	6	40	5.7	18.4	2.6	1.5	0.6	0.6	2.2	31.6
			60	5.7	18.4	3.9	1.5	0.6	0.6	2.2	32.9
			80	5.7	18.4	5.3	1.5	0.6	0.6	2.2	34.3
		12	40	5.7	30.2	2.6	1.5	1.1	0.6	3.8	45.5
			60	5.7	30.2	3.9	1.5	1.1	0.6	3.8	46.8
			80	5.7	30.2	5.3	1.5	1.1	0.6	3.8	48.2
		15	40	5.7	36.2	2.6	1.5	1.3	0.6	4.6	52.5
			60	5.7	36.2	3.9	1.5	1.3	0.6	4.6	53.8
			80	5.7	36.2	5.3	1.5	1.3	0.6	4.6	55.2
	2.50	6	40	7.1	19.9	2.6	1.5	0.7	0.6	2.2	34.6
			60	7.1	19.9	3.9	1.5	0.7	0.6	2.2	35.9
			80	7.1	19.9	5.3	1.5	0.7	0.6	2.2	37.3
		12	40	7.1	33.0	2.6	1.5	1.1	0.6	3.9	49.8
			60	7.1	33.0	3.9	1.5	1.1	0.6	3.9	51.1
			80	7.1	33.0	5.3	1.5	1.1	0.6	3.9	52.5
		15	40	7.1	39.5	2.6	1.5	1.4	0.6	4.7	57.4
			60	7.1	39.5	3.9	1.5	1.4	0.6	4.7	58.7
			80	7.1	39.5	5.3	1.5	1.4	0.6	4.7	60.1
	5.0	6	40	11.5	24.4	2.6	1.5	0.7	0.6	2.4	43.7
			60	11.5	24.4	3.9	1.5	0.7	0.6	2.4	45.0
			80	11.5	24.4	5.3	1.5	0.7	0.6	2.4	46.4
		12	40	11.5	41.0	2.6	1.5	1.3	0.6	4.2	62.7
			60	11.5	41.0	3.9	1.5	1.3	0.6	4.2	64.0
			80	11.5	41.0	5.3	1.5	1.3	0.6	4.2	65.4
		15	40	11.5	49.3	2.6	1.5	1.5	0.6	5.1	72.1
			60	11.5	49.3	3.9	1.5	1.5	0.6	5.1	73.4
			80	11.5	49.3	5.3	1.5	1.5	0.6	5.1	74.8

BI-MODE ENGINE
2000 SECONDS

P_c	CR	L'	Ae/At	Weight-lb Injector	Comb. Chbr.	Nozzle	Gimb. Ring	Gimb. Supt.	Noz. Clamp	Insulation	Total
200	1.5	6	40	4.4	15.4	1.7	1.5	0.6	0.6	2.1	26.3
			60	4.4	15.4	2.5	1.5	0.6	0.6	2.1	27.1
			80	4.4	15.4	3.3	1.5	0.6	0.6	2.1	27.9
		12	40	4.4	25.2	1.7	1.5	1.0	0.6	3.6	38.0
			60	4.4	25.2	2.5	1.5	1.0	0.6	3.6	38.8
			80	4.4	25.2	3.3	1.5	1.0	0.6	3.6	39.6
		15	40	4.4	30.1	1.7	1.5	1.3	0.6	4.4	44.0
			60	4.4	30.1	2.5	1.5	1.3	0.6	4.4	44.8
			80	4.4	30.1	3.3	1.5	1.3	0.6	4.4	45.6
	2.50	6	40	5.4	16.4	1.7	1.5	0.6	0.6	2.1	28.3
			60	5.4	16.4	2.5	1.5	0.6	0.6	2.1	29.1
			80	5.4	16.4	3.3	1.5	0.6	0.6	2.1	29.9
		12	40	5.4	27.1	1.7	1.5	1.1	0.6	3.7	41.1
			60	5.4	27.1	2.5	1.5	1.1	0.6	3.7	41.9
			80	5.4	27.1	3.3	1.5	1.1	0.6	3.7	42.7
		15	40	5.4	32.4	1.7	1.5	1.3	0.6	4.5	47.4
			60	5.4	32.4	2.5	1.5	1.3	0.6	4.5	48.2
			80	5.4	32.4	3.3	1.5	1.3	0.6	4.5	49.0
	5.0	6	40	8.4	19.5	1.7	1.5	0.7	0.6	2.2	34.6
			60	8.4	19.5	2.5	1.5	0.7	0.6	2.2	35.4
			80	8.4	19.5	3.3	1.5	0.7	0.6	2.2	36.2
		12	40	8.4	32.6	1.7	1.5	1.2	0.6	3.9	49.9
			60	8.4	32.6	2.5	1.5	1.2	0.6	3.9	50.7
			80	8.4	32.6	3.3	1.5	1.2	0.6	3.9	51.5
		15	40	8.4	39.1	1.7	1.5	1.4	0.6	4.7	57.4
			60	8.4	39.1	2.5	1.5	1.4	0.6	4.7	58.2
			80	8.4	39.1	3.3	1.5	1.4	0.6	4.7	59.0

APPENDIX C

BIMODAL ENGINE, LIGHTWEIGHT THRUST CHAMBER

I. BIMODAL ENGINE, LIGHTWEIGHT THRUST CHAMBER

A. DESIGN SELECTION

The use of a duct cooled thrust chamber results in a bimodal engine (see Figure C-1) which has the following features:

- Its weight is not related to its duration capability.
- It weighs 16.4 pounds less than a bimodal engine with an ablative thrust chamber at baseline[1] conditions.

These advantages may require an increase in fuel barrier flow to provide thermal protection at the thrust chamber to injector interface area. This could result in a 3.6 sec I_{sp} decrement from the baseline design.

B. DESIGN JUSTIFICATION

The thrust chamber configuration (Ref. Figure 2) selected for the bimodal engine point design[1] represents the current state-of-the-art for passively cooled thrust chambers. Its primary disadvantage is that its duration capability is directly related to its weight.

Alternate designs were examined. One considered the use of a self-supporting free-standing graphite throat and nozzle such as described in Category III of Figure C-2. This design was found to have three potential shortcomings. These are (1) the need to fabricate the liner as a single piece which increases its cost and vulnerability to damage in handling, (2) the necessity for pyrolyzing materials at the attachment of the liner and injector, and (3) the duration dependence of the ablative attachment collar's weight.

(1) Baseline engine $P_c = 120$, $\varepsilon = 60/1$, $Ac/At = 2.25$.

260

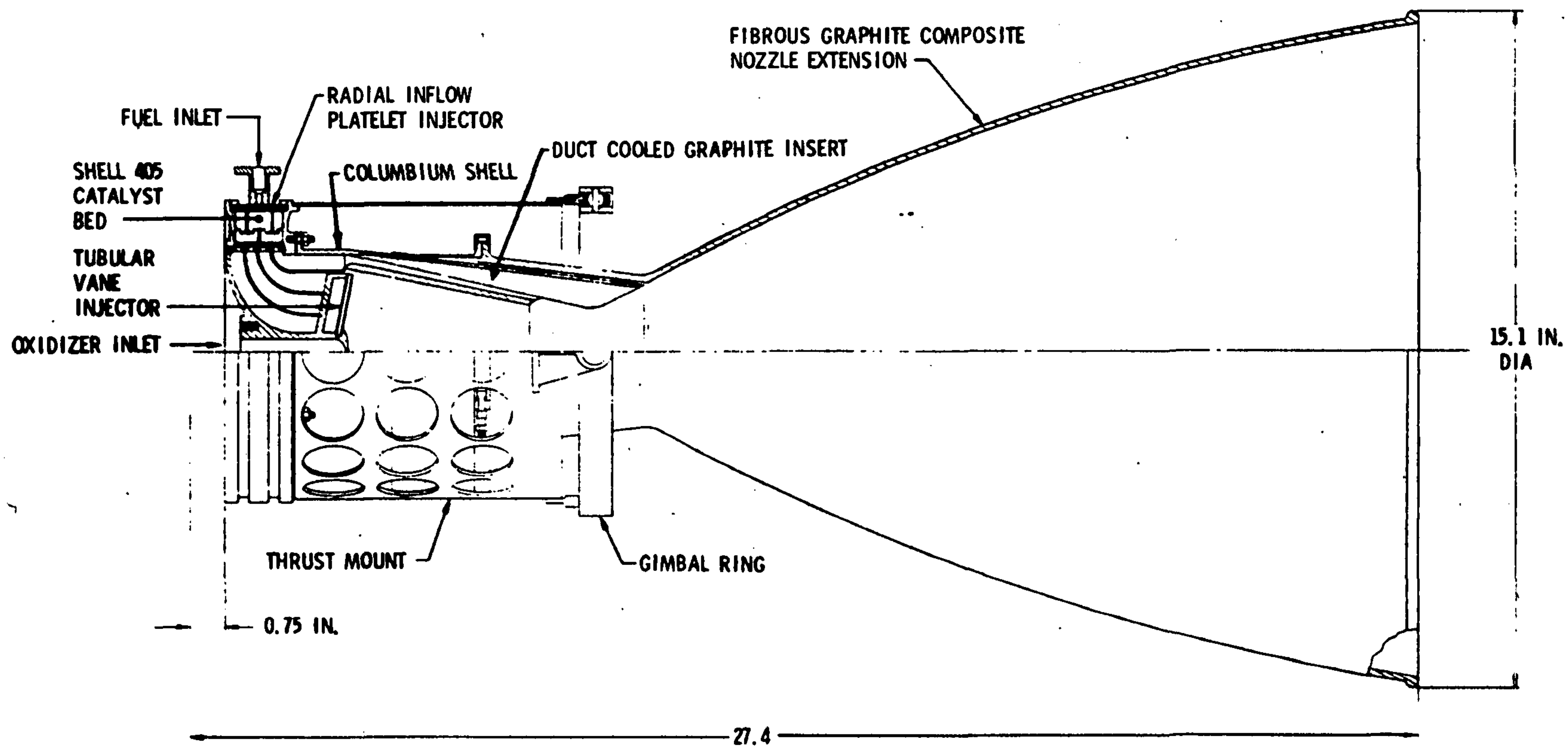


Figure C-1. Light-Weight Duct-Cooled Bimodal Engine

262

CATEGORY I	GRAPHITE PHENOLIC FLAME LINERS, SILICA PHENOLIC INSULATION, EXTERNAL STRUCTURAL MEMBER.
	LIMITED DURATION CAPABILITY
	FAILURE MODE - FLAME SURFACE REGRESSION
CATEGORY II	EROSION RESISTANCE FLAME SURFACES: BULK GRAPHITE, PG, PYROCARB AND AGcarb ARE CONTAINED WITHIN GRAPHITE-PHENOLIC & SILICA-PHENOLIC INSULATION SYSTEMS; EXTERNAL STRUCTURAL MEMBER
	DEMONSTRATED DURATIONS APPROACHING 1000 SEC
	FAILURE MODES - LOCAL STREAKING, CRACKING AND NON-RETENTION OF LINER; LIMIT CONDITION - SILICA INSULATION MELTS
	DESIGN DEFICIENCY - WALL THICKNESS INCREASE WITH DURATION
CATEGORY III	FLAME SURFACE & STRUCTURE ARE SYNONYMOUS
	FAILURE MODE - MECHANICAL FAILURE OF LINER
	DESIGN DEFICIENCY - NO REDUNDANCY OF STRUCTURE; - MATERIALS PROPERTIES ARE CRITICAL - DIFFICULT ATTACHMENT AT INJECTOR INTERFACE

Figure C-2. Thrust Chamber Development Status

Figure C-1 illustrates a duct cooled thrust chamber concept which provides solutions to each of these disadvantages. This thrust chamber utilizes a fibrous graphite composite liner which is contained in a columbium shell. The metal case provides a backup structure eliminating the need for the liner to be self-supporting. In addition, it permits the nozzle extension which is fabricated as a separate part to be mechanically attached.

The coolant slots and the chamber liner shape insures that thermal energy which flows in an upstream direction is absorbed by the gaseous coolant passing through the slots. The slotted sleeve also minimizes radial heat flow from the chamber's gas-side surface. The coolant discharged from the slots film cools the throat of the unit. Hence, the chamber liner utilizes film cooling, inter-regen cooling and regenerative coolant to maintain a suitable gas-side and backside wall temperature.

This coolant system eliminates the need for pyrolyzing materials and makes the thrust chamber weight independent of its operating duration. The use of the relatively thin chamber wall provides a substantial weight saving over the more conventional ablative thrust chamber design.

In addition, the thinner wall chamber reduces the gimbal ring diameter and the diameter of the injector attachment flange for a further weight advantage. These features are shown in the following summary of point design engine weights.

Component Description	Component Weight, lb Conventional Ablative	Component Weight, lb Duct Cooled
Thrust Chamber	16.4	4.2
Nozzle Extension	5.6	4.0
Chamber-Nozzle Clamp	0.6	0.4
Injector Assembly	8.6	6.0
Gimbal Ring	1.5	1.0
Thrust Mount	0.7	0.6
Dyna Quartz Insulation	2.2	3.0
Total	35.6	19.20

The duct cooled thrust chamber is dependent upon film cooling flow through the duct for its operation. Several coolant flow rates were examined and their effect upon gas-side wall temperature calculated. It was assumed that the combustion zone upstream of the duct outlet is not film cooled with the result that the recovery temperature at the gas side wall of the duct is about 7000°F. The duct wall temperatures and coolant temperatures are shown in Figure C-3. The throat and nozzle wall temperatures are several hundred degrees lower than that of the coolant due to radiation and axial conduction effects.

As indicated in Figure C-3 the 15 percent film coolant flow rate is necessary to maintain a 4000°F throat temperature and to prevent adverse heat flow to the bimodal injector and reactor. Using the performance film coolant relation shown in Figure C-4 the engine incorporating the duct cooled thrust chamber is forcasted to have an I_{sp} of 378.4 sec. This results in the following engine performance-weight tradeoff.

	Engine Weight	Engine I_{sp}
Ablative Thrust Chamber	35.6 lb	382.0 sec
Duct Cooled Thrust Chamber	19.2 lb	378.4 sec
	Δ = 16.4 lb	Δ = 3.6 sec

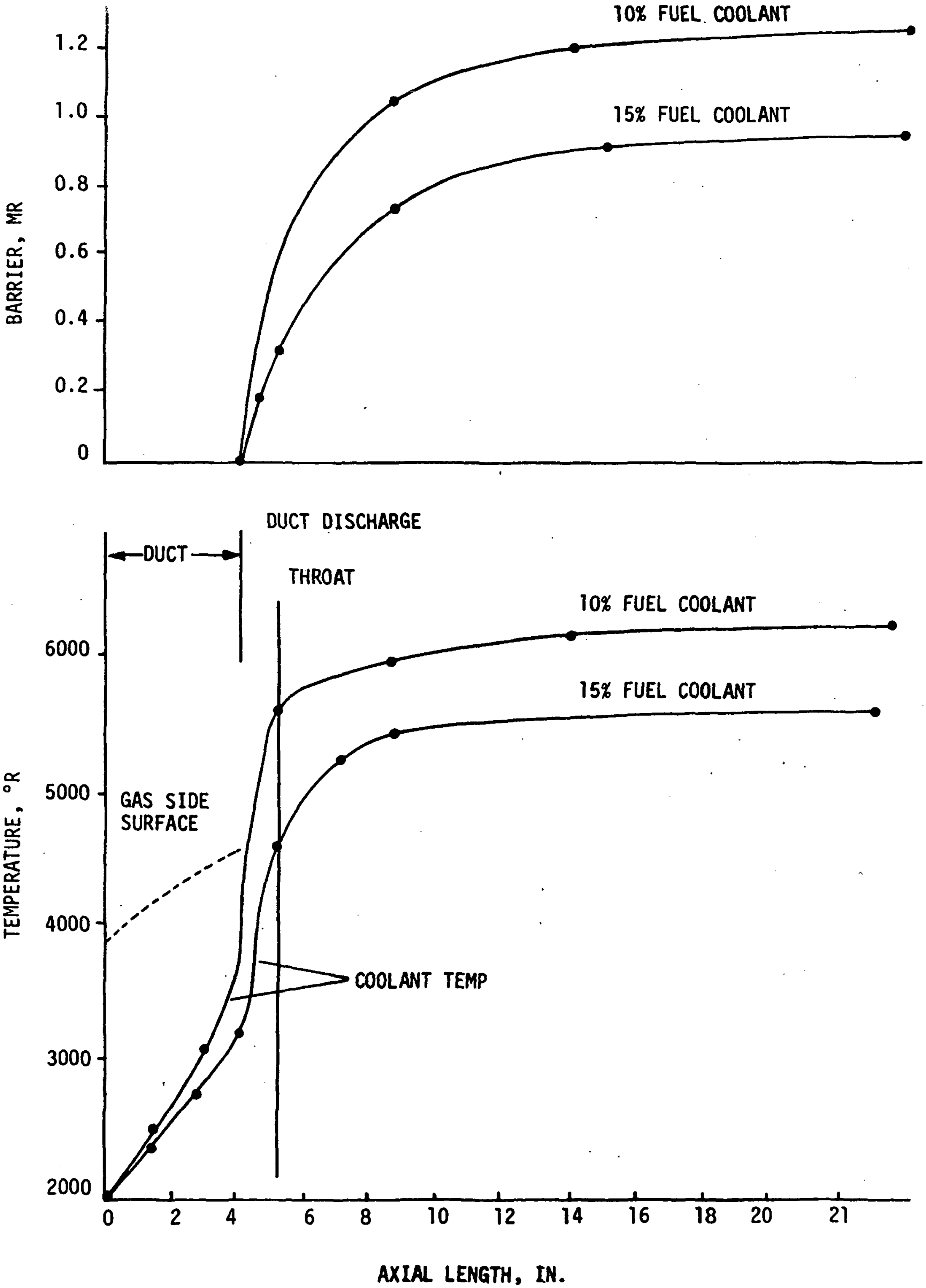


Figure C-6. Duct Cooled FL/N_2H_4 Engine

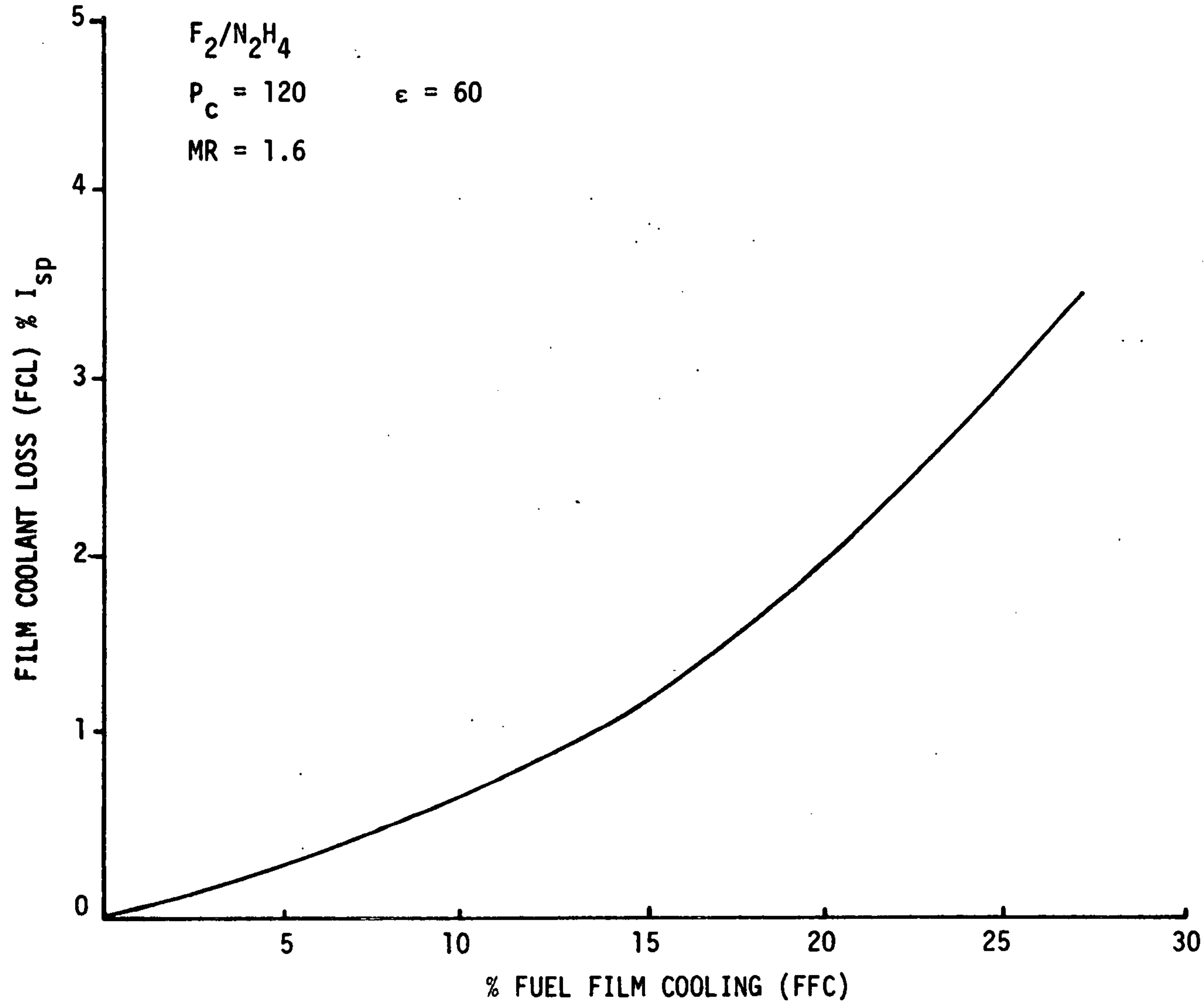


Figure C-4. Comparison Study of F_2/N_2H_4 Engine Concepts Performance Analysis, Film Coolant Losses

APPENDIX D

LIQUID-LIQUID ENGINE TRANSVERSE PLATELET INJECTOR

Design Selection

When compared to the bimodal engine the liquid-liquid engine suffers a performance decrement and increased weight due to the added combustion chamber length needed for the atomization and vaporization of the fuel.

The transverse platelet injector concept (see Figure D-1) provides a proven injector configuration which by means of low thrust/element and mechanical atomization of the fuel, will achieve rapid fuel vaporization as illustrated in Figure D-2. The improved fuel vaporization allows the combustion chamber length (L') of the baseline liquid-liquid engine to be reduced from 12.0 to 6.0 inches with an attendant reduction in film coolant requirements as indicated in Figure D-3. This results in the following liquid-liquid engine operating characteristics.

	L'	I_{sp}	Engine Weight
Like-Doublet Injector	12.0 in.	379.8 sec	48.0 lb
Transverse Platelet Injector	6.0 in.	382.3 sec	35.0 lb

Design Justification

The transverse platelet injector concept and the splash plate element intended for use on the LF_2/N_2H_4 liquid-liquid engine are illustrated in Figure D-1. The selected element is an outgrowth of the ALRC injector developed on Air Force Rocket Propulsion Laboratory Contract F04611-73-C-0061 for a Five Pound Thrust Bipropellant Engine. This design, which operated with N_2O_4/MMH propellants, accumulated over 400,000 firings and made a continuous duration firing of over 6000 seconds.

The conversion of the transverse platelet injector to LF_2/N_2H_4 propellants and the scale up of the 5-LbF engine element design is quite straight forward. The following changes are required:

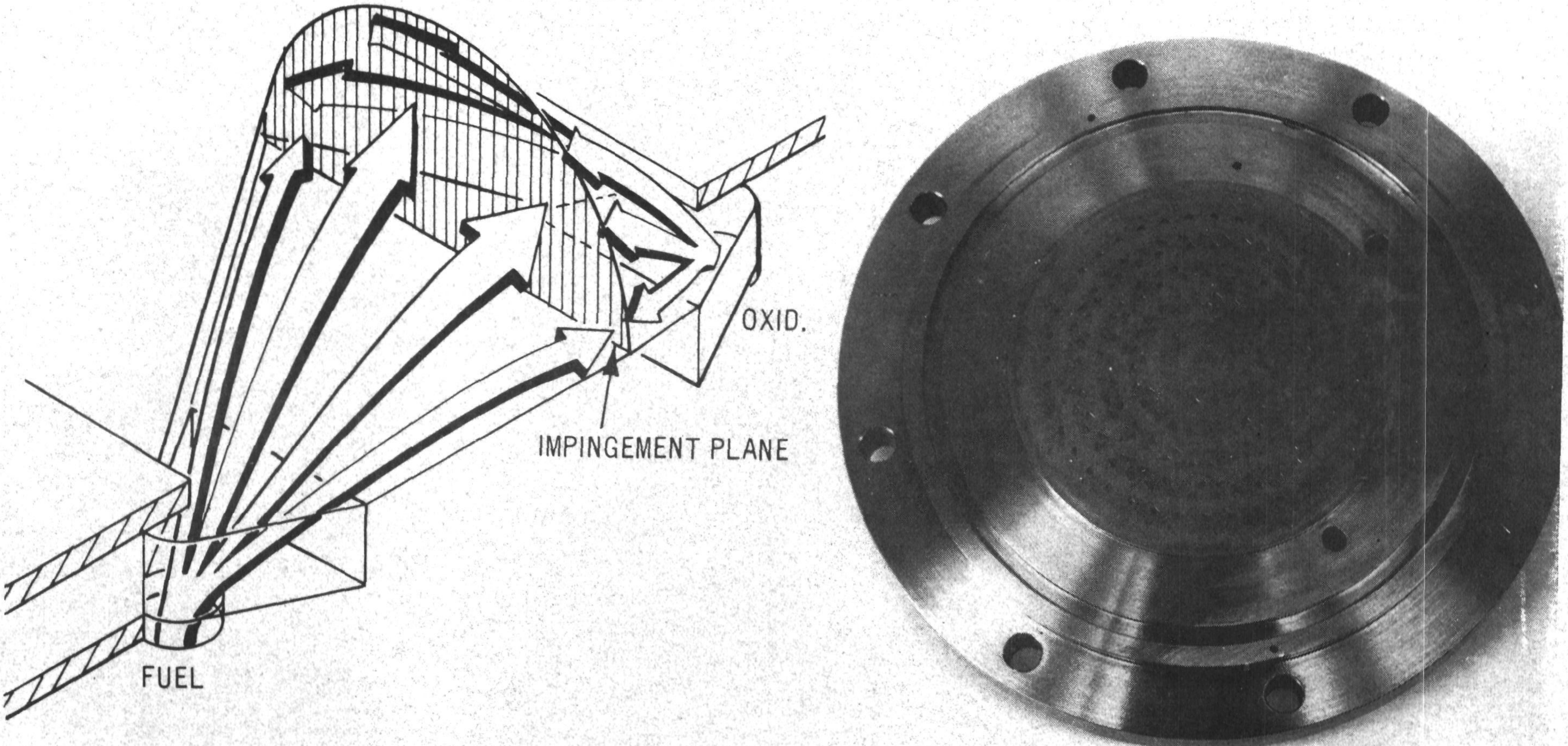


Figure D-1 Transverse Platelet Injector

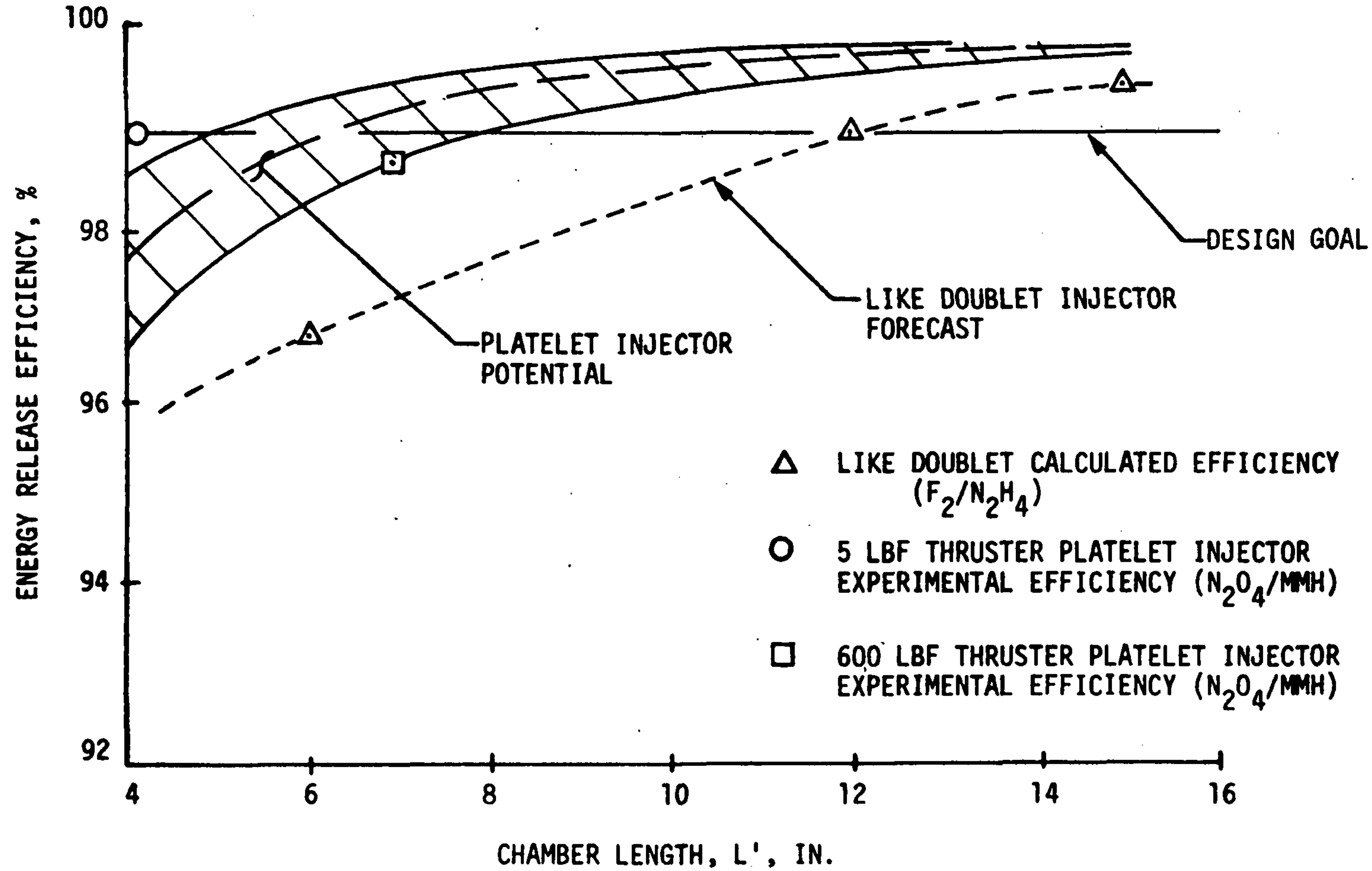


Figure D-2. Performance Analysis, Liquid-Liquid Injector

271

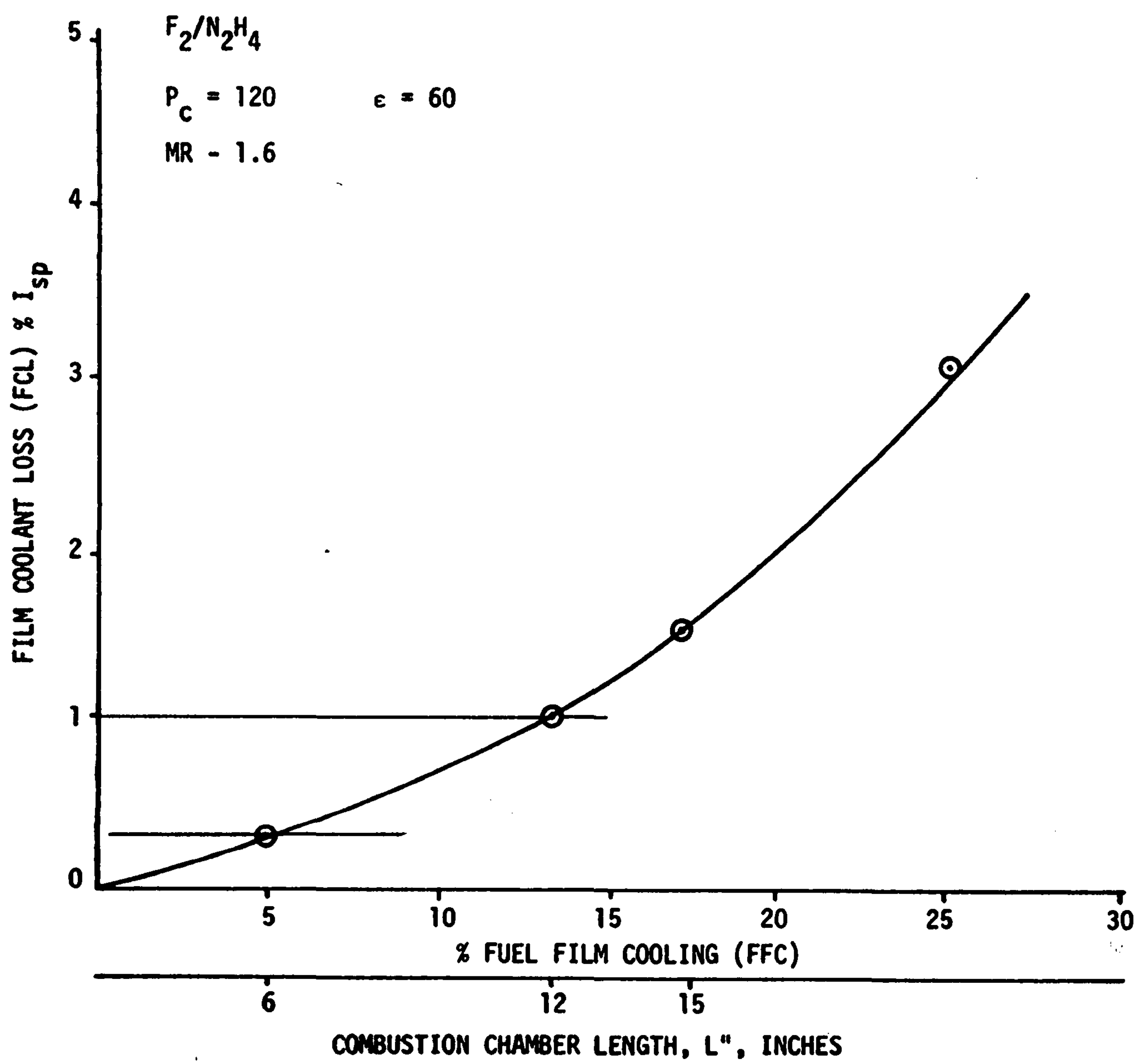


Figure D-3. Performance Analysis, Film Coolant Losses

272

(1) The use of 700 elements at the 600-LbF thrust level.

(2) Conversion of the stainless steel face plates to Nickel-200.

(3) The design of a manifold system suited to the flow rate of the 600-lbF engine.

The element quantity increase in straight forward entailing modification of the art work used in the photo etching of the 5-lbF injector elements. The photo etching and bonding processes have already been demonstrated on OME (NAS 9-13133) 600-lbF and 6000-lbF injectors.

The change-over to Nickel-200 in place of the stainless steel customarily used on N_2O_4 systems, has already been proven by the successful fabrication of platelet injectors designed for operation with OF_2/B_2H_6 and ClF_5/MMH propellants. The 1000 lbF diborane injectors were developed on Contract NAS 7-713 for NASA-JPL. The ClF_5/MMH injectors were 25 lbF units which were evaluated by AFRPL[1].

The 5-lbF engine has the injector manifolding (propellant feed system) contained within the bonded photo etched platelet assembly. This is due to a need for the very small dribble volume necessary to 0.05 lb-sec impulse bits. The proposed 600-lbF LF_2/N_2H_4 injector would use a ring manifold system similar to that developed for the 600-lbF subscale OME engine.

Experience obtained with splash plate elements on the 600 lbF OME injector discloses that as atomization and mixing efficiencies are improved, the maintainance of dynamic combustion stability requires the use of acoustic cavities to provide combustion damping. Since these stabilization systems have been used with complete success on the 600-lbF and 6000-lbF N_2O_4/MMH OME engines as well as a 3000 lbF N_2O_4/N_2H_4 engine, their incorporation into the LF_2/N_2H_4 liquid-liquid engine's injector can be accomplished with complete

(1) Report AFRPL-TR-69-156 Advanced Storable (ClF_5/MMH) ACS Propulsion by Capt D. A. Schantz and P. T. Butler; August 1969.

213

confidence. The acoustic damper cavity of the 600-lbF OME engine has a depth of 0.60 in. and an operative width of 0.19 in. The LF_2/N_2H_4 damper will be of a similar size.

274