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(TITLE UNCLASSIFIED)

THROTTLING AND SCALING STUDY FOR ADVANCED STORABLE ENGINE

Report 68-C-0008-F

Part 2 of Two Parts
APPENDIX I
ARES SIZE SCALING DATA

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J. A. Gibb
A. W. Nelson

AEROJET-GENERAL CORPORATION
ADVANCED STORABLE ENGINE PROGRAM DIVISION
LIQUID ROCKET OPERATIONS
SACRAMENTO, CALIFORNIA

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FIGURE LIST

I.
INTRODUCTION

(U) The Advanced Rocket Engine Storable (ARES), described in this appendix, is a throttlable-restartable advanced rocket engine using storable N_2O_4/ AeroZINE 50 propellants. The engine features high performance and simplicity in design. ARES is presently in the process of advanced development testing at Aerojet-General Corporation under contract to the USAF Rocket Propulsion Laboratory, Edwards AFB, California (Contract AF 04(611)-10830). Testing is at a fixed thrust of 100K.

(U) Parametric performance, size, weight, and cost scaling data for throttlable and restartable ARES liquid-propellant rocket engines over a range of engine sizes with rated thrust values from 25,000 to 500,000 lbf are presented in this report.

II.

ARES ENGINE DESCRIPTION

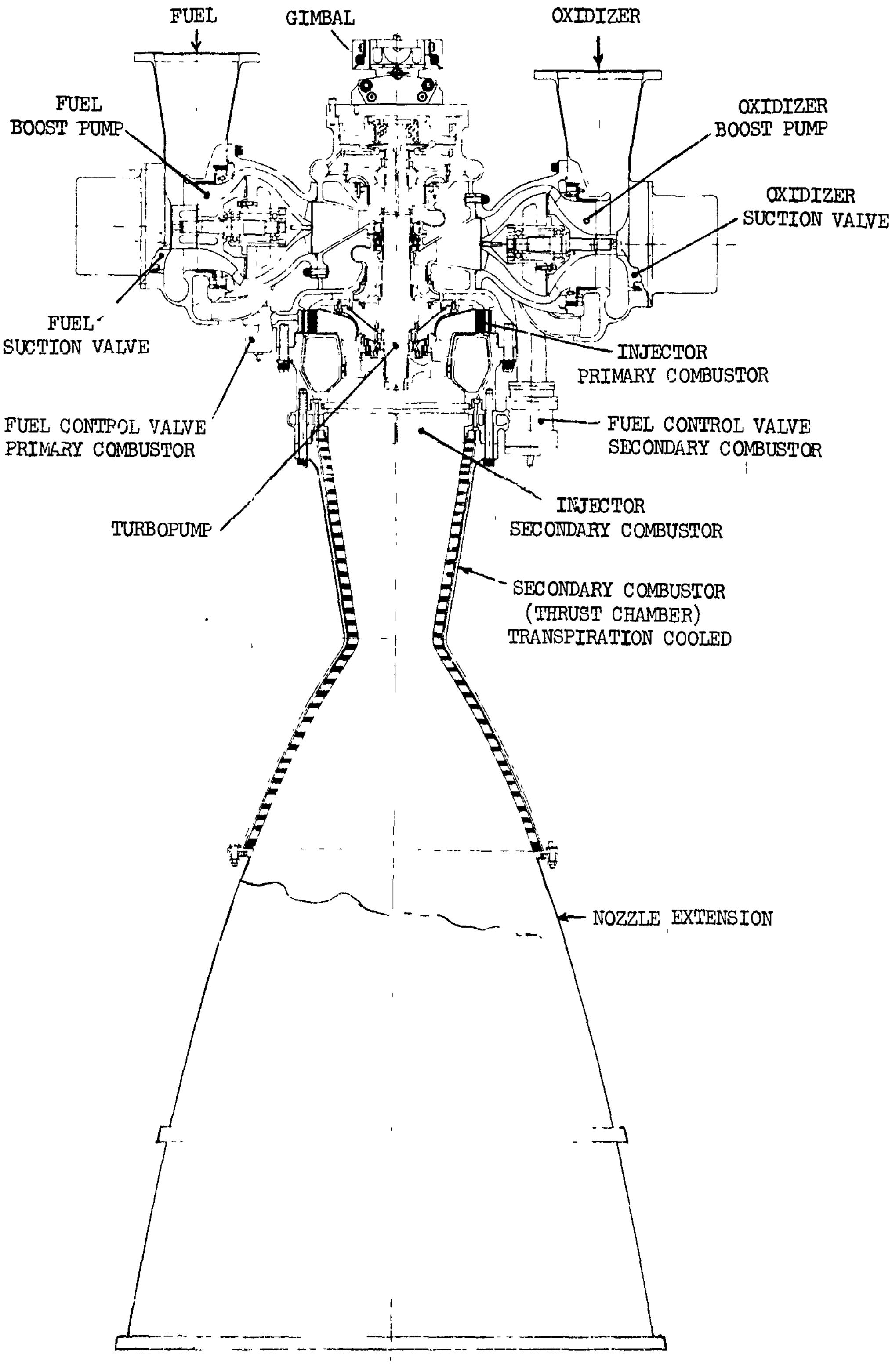
(U) The ARES engine shown in Figure II-1-A consists of a turbopump assembly, a thrust chamber assembly, fuel and oxidizer suction valves, and boost pumps. The turbopump assembly includes the main pumps, the turbine, the primary combustor, and two fuel control valves, and forms the central structure of the engine. The turbopump is mounted on top of the thrust chamber, with thrust being transmitted through the turbopump housing to the gimbal and airframe. The entire engine is gimbaled from a gimbal assembly which is attached to the thrust take-out pad of the engine.

(U) The turbine, oxidizer pump, and fuel pump are on a single shaft which is in line with the engine thrust axis and is supported in the housing by propellant-lubricated bearings. The single-stage turbine is on the lower end of the shaft and exhausts directly into the thrust chamber. The single-stage oxidizer pump is on the center of the shaft, with the two-stage fuel pump on the top end. Fuel and oxidizer enter the engine through vertical inlets on each side of the turbopump. In each suction inlet, a hydraulically driven boost pump is mounted with its shaft horizontal. A suction prevalve is located upstream of each boost pump.

(U) The primary combustor utilizes a radial inflow HIPERTHIN* injector consisting of a stack of thin platelet washers, with fuel and oxidizer fed between and metered by alternate washers.

(U) The secondary combustor, or thrust chamber, is transpiration cooled to the throat and downstream of the point where static pressure is 30 psia; from that point on the extension nozzle is cooled by the coolant-carryover boundary layer. The transpiration-cooled thrust chamber utilizes platelet washers for metering the required amounts of oxidizer into the thrust chamber wall. The nozzle extension is similar in design to the nozzle on the Apollo service module engine and the Transtage engine.

*Aerojet design denoting High Performance Throttlable Injector.



ARES Engine 100K, Throttlable (u)

Figure II-1-A

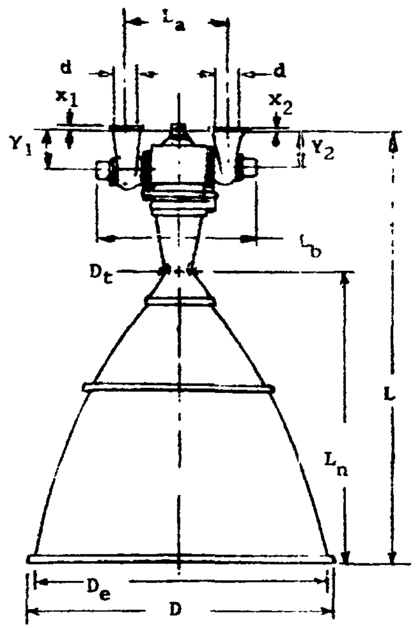
III.
SCALING DATA

(C) Design scaling data have been determined for throttlable, restartable ARES engines at three rated thrust levels of 25K, 100K, and 500K, Figure III-1-A shows the predicted performance, weights, and dimensions for each of the three engines incorporating thrust chambers with 50:1 area ratio 80% bell contour and 150:1 area ratio RAO contour nozzles. The engine specific impulse values are based on the Contract AF 04(611)-10830 target performance of 91.7% of theoretical. Detailed thermodynamic analysis has shown that up to 94% specific impulse efficiency can be reasonably achieved in a development program. Therefore, the specific impulse data presented are conservative.

(U) Predicted engine performance (vacuum and sea level) versus nozzle area ratio is shown in Figure III-2-A for the three design thrust levels. Predicted engine throttling performance for the three engines over a 10:1 throttle range is shown in Figure III-3-A. The reduction in specific impulse as the engine is throttled results from: (1) increased combustion loss because of the lower liquid injection velocity and lower fuel vaporization rate, (2) increased friction because of greatly reduced flow over the same area, and (3) increased kinetic losses because of gas disassociation. Engine dry and wet weights versus rated vacuum thrust are shown by Figures III-4-A and III-5-A, respectively. It can be noted that the engines with 50:1 area ratio nozzles are slightly heavier than those with 150:1 area ratio nozzles. This results from the fact that as the area ratio is increased from 50:1, engine weight increases but thrust increases at a faster rate. Engine length and maximum diameter values versus thrust are shown by Figure III-6-A. The dimension ratios for RAO and 80% bell contour thrust chamber nozzles are presented in Figure III-7-A. Engine gimbal moment of inertia versus rated thrust is shown in Figure III-8-A. Estimated cost (1967 dollars) to develop man-rated, throttlable, restartable ARES engines is shown in Figure III-9-A. These costs are based on a four-year program involving three years through PFRT and one

III, Scaling Data

year for qualification. Propellant costs are shown separately. Fee is not included in the estimate. Estimated unit production cost (1967 dollars) for throttlable, restartable ARES engines is shown in Figure III-10-A. Costs shown do not include propellants or fee.

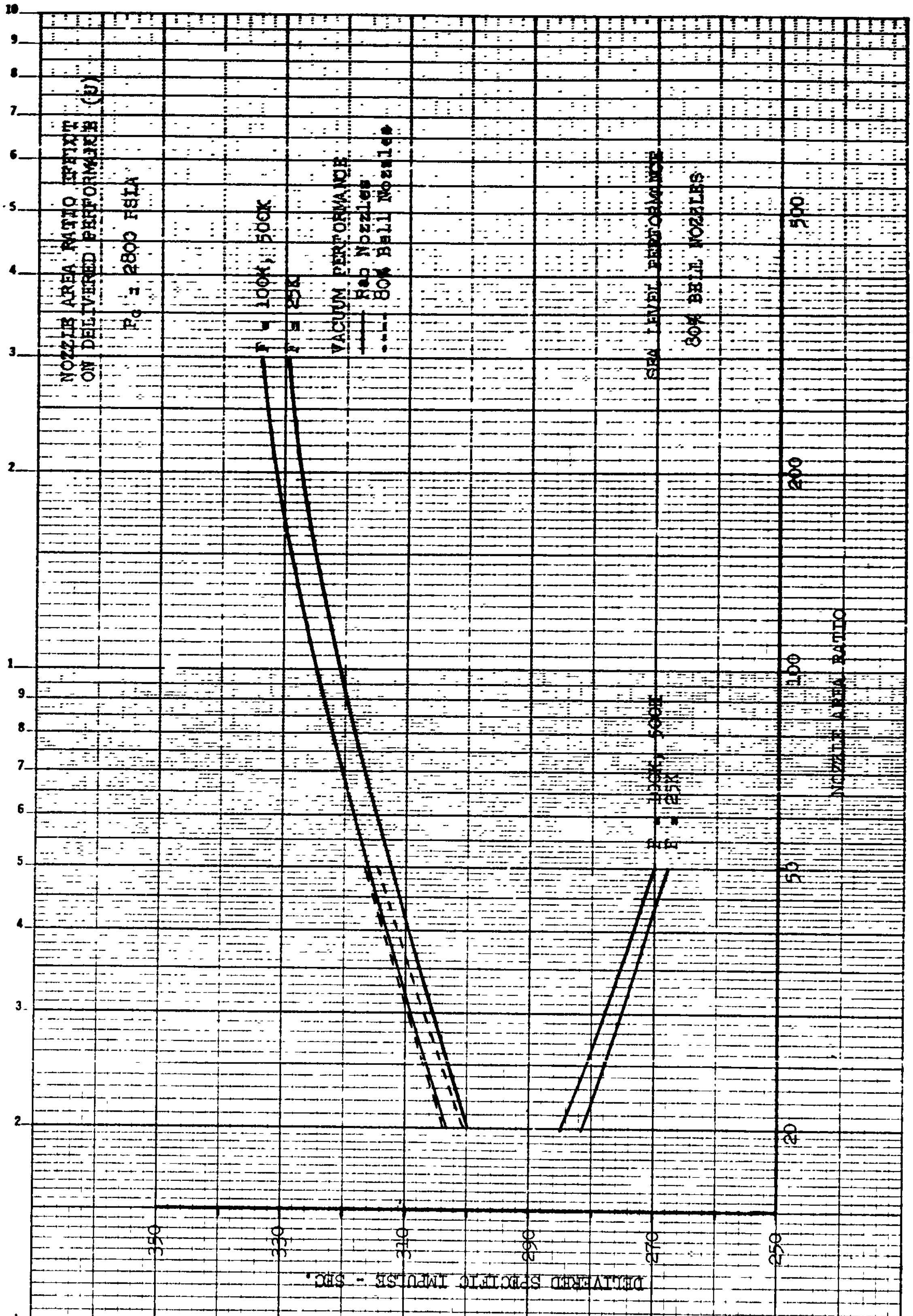


	25K		100K		500K	
	€ = 50 80% Bell	€ = 150 RAO	€ = 50 80% Bell	€ = 150 RAO	€ = 50 80% Bell	€ = 150 RAO
F, Vacuum Thrust, lbf	24,200	25,000	111,065	115,250	582,200	604,100
I_s vac, sec	314.5	324.6	316.5	328.4	316.5	328.4
I_s efficiency, %	91.1	90.3	91.7	91.2	91.7	91.2
P_c, psia	2,800	2,800	2,800	2,800	2,800	2,800
MR_{eng}	2.465	2.465	2.427	2.427	2.427	2.427
L*	24.7	24.7	26.7	26.7	30.6	30.6
N_T (speed), rpm	64,000	64,000	30,000	30,000	13,150	13,150
NPSH oxid/fuel, ft.*	20	20	20	20	20	20
Weight Dry, lb	207	209	869	883	6,110	6,130
Weight Wet, lb	215	217	933	946	6,811	6,828
L, Overall, in.	43.232	59.532	84.334	119.334	179.74	260.14
L, Overall, in.	18.2	30.88	38.8	66.08	88.9	151.0
d, in.	2.9	2.9	5.8	5.8	13.2	13.2
L_a, in.	14.0	14.0	28.0	28.0	64.0	64.0
L_b, in.	22.4	22.4	44.8	44.8	102.0	102.0
Y_1, in. (Fuel)	5.1	5.1	10.25	10.25	23.4	23.4
Y_2, in. (Oxidizer)	5.1	5.1	11.3	11.3	25.9	25.9
X_1, in. (Fuel)	.65	.65	1.25	1.25	2.8	2.8
X_2, in. (Oxidizer)	.65	.65	0.2	0.2	0.4	0.4
D_t, nozzle throat, in.	2.43	2.43	5.214	5.214	11.9	11.9
D_e, nozzle exit, in. (I.D.)	17.2	29.78	36.8	63.88	84.5	146.3
L_n, in.	21.9	38.2	47.0	82.0	107.6	188.0
Gimbal Moment of Inertia, Wet Slug $Ft.^2$	10.0	13.9	176	250	4,531	6,563

*With Boost Pumps

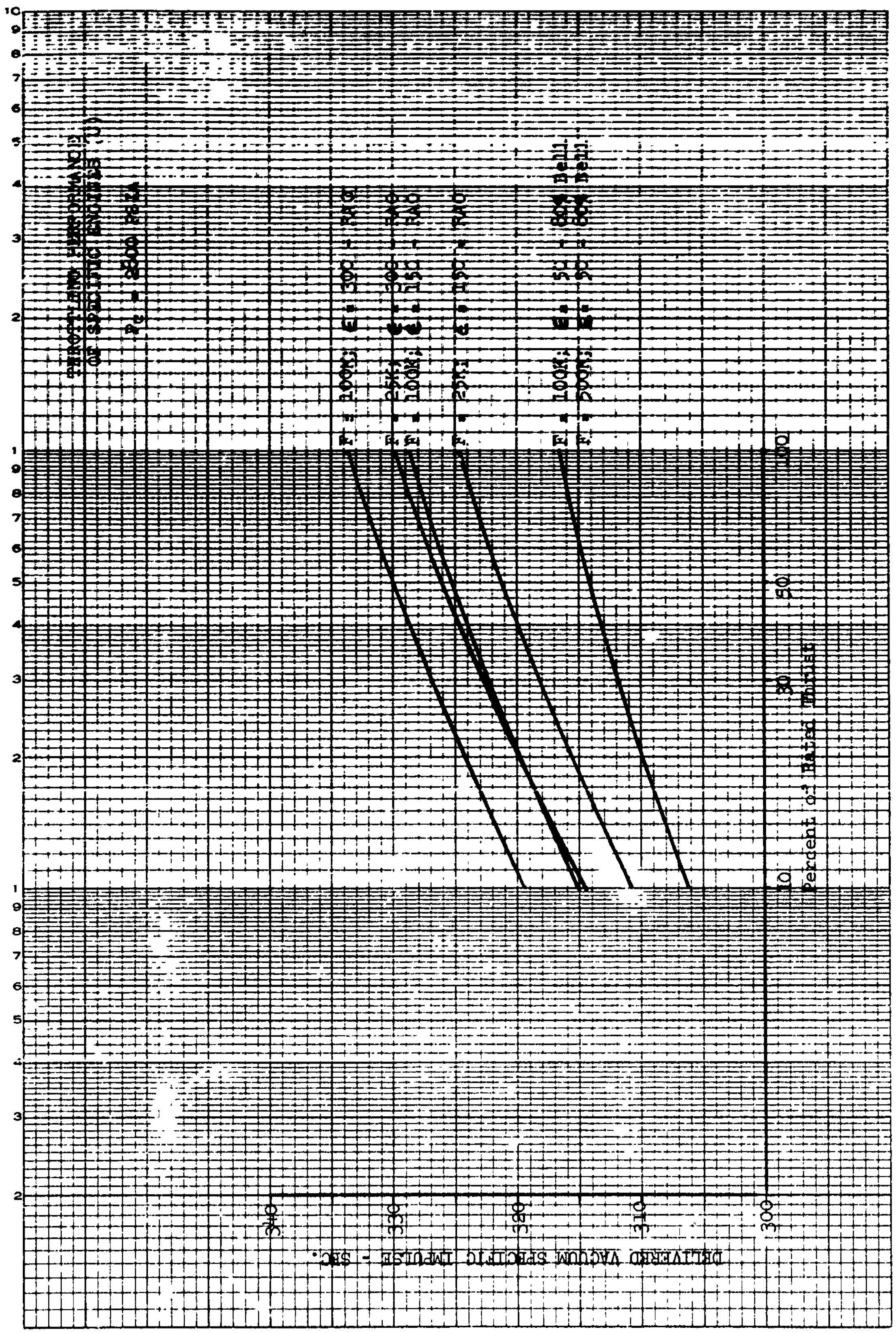
ARES Scaling Design Point Data (u)

Figure III-1-A



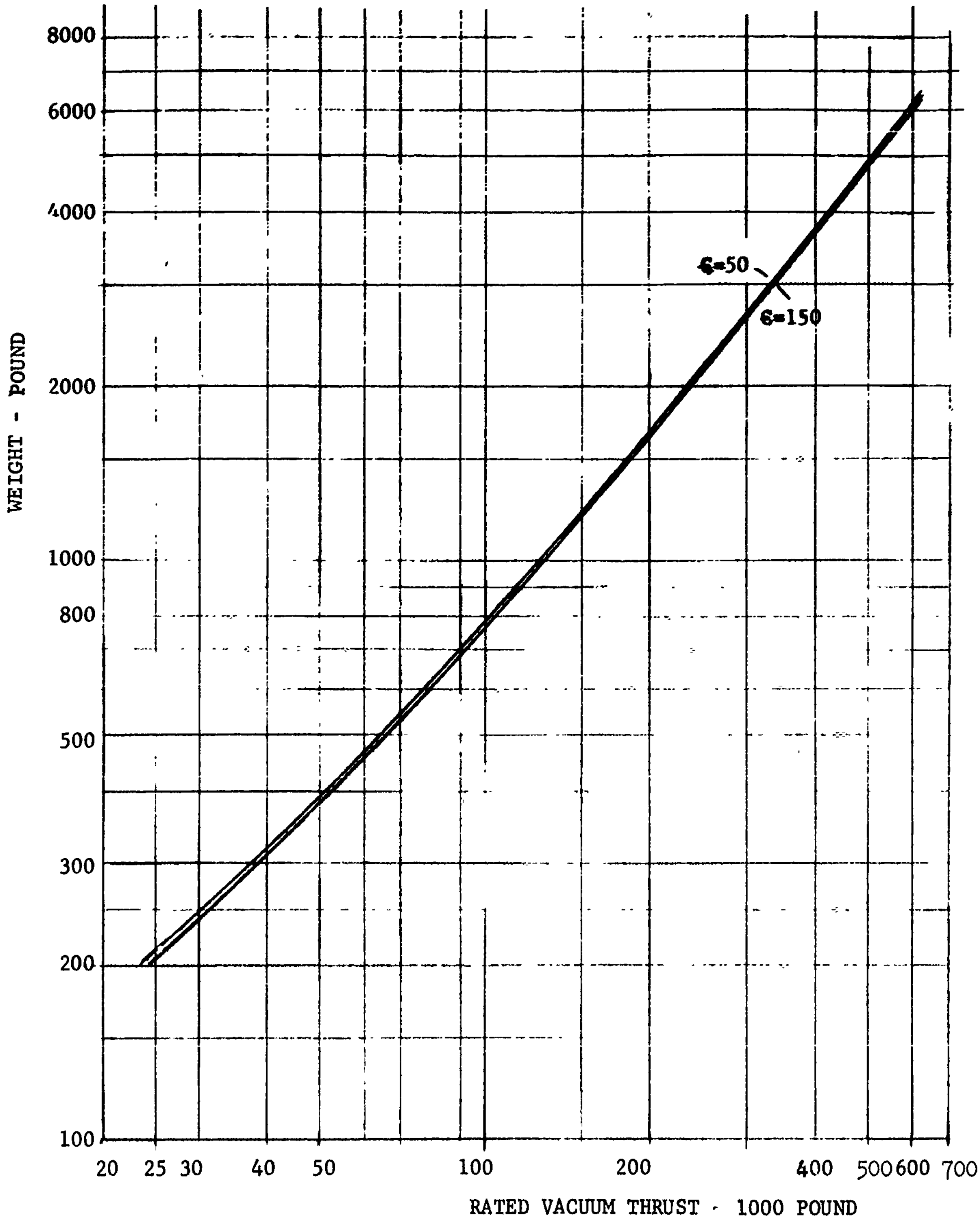
Nozzle Area Ratio Effect on Delivered Performance (u)

Figure III-2-A



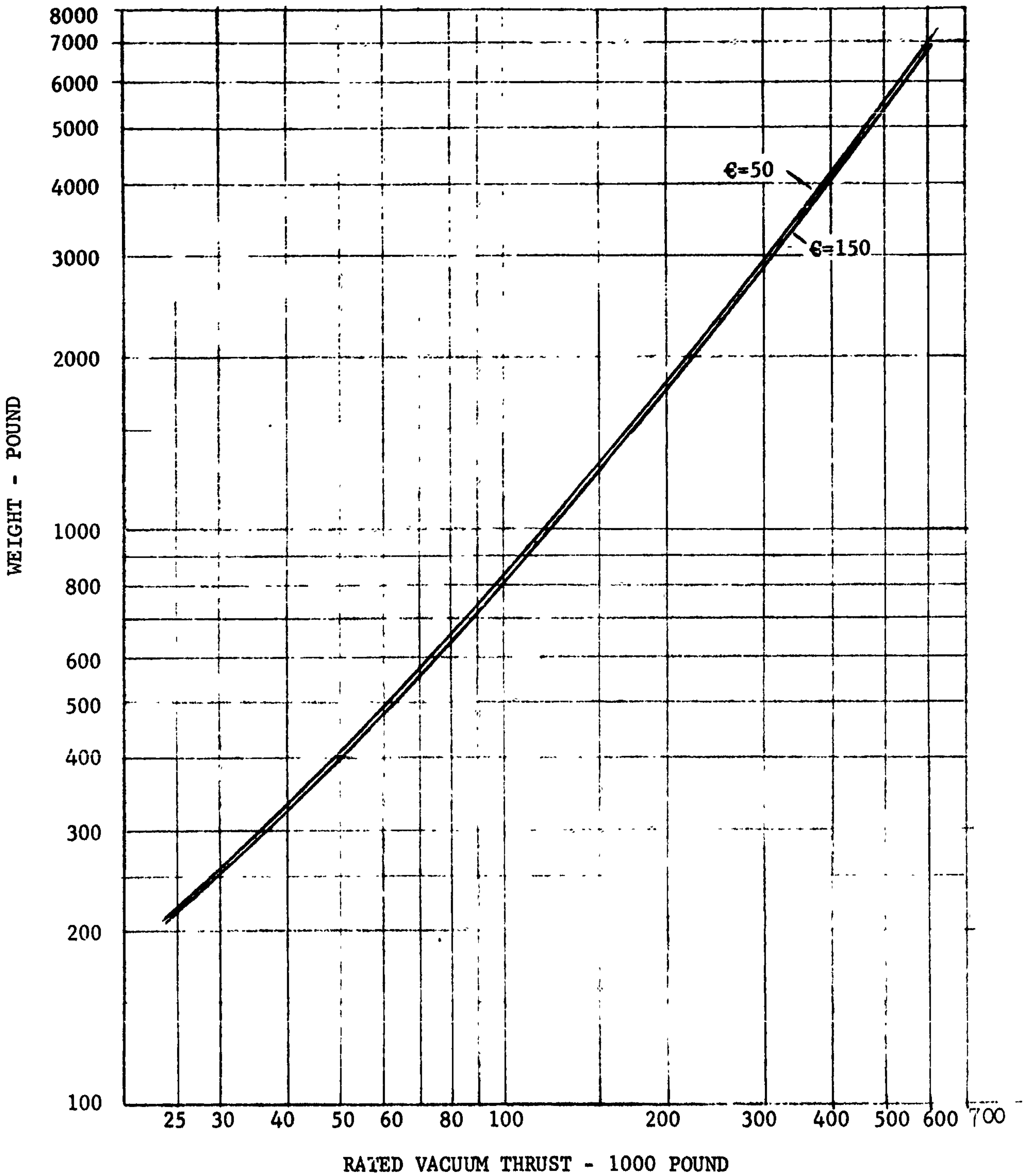
Throttling Performance of Specific Engines (u)

Figure III-3-A



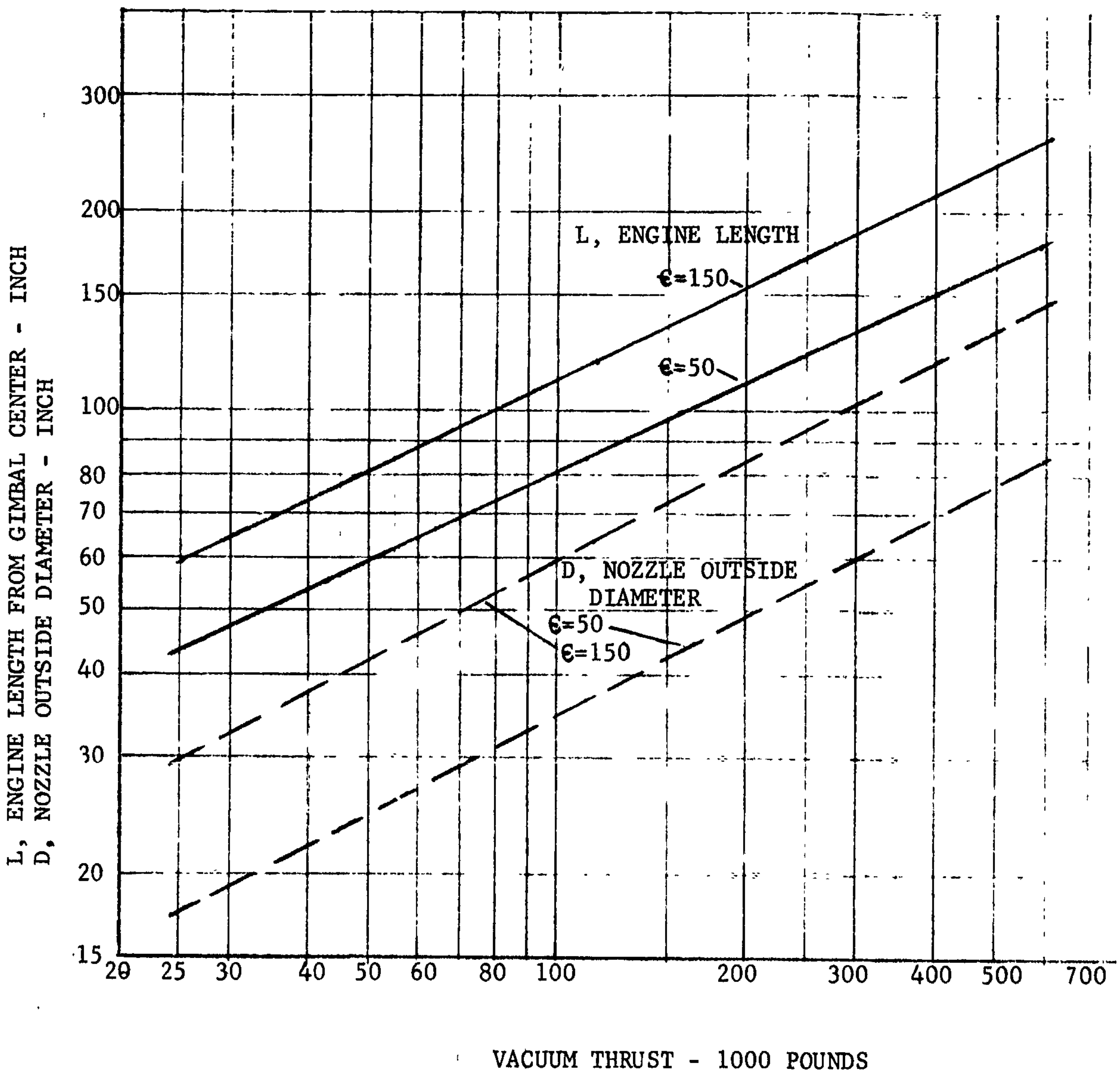
ARES Dry Weight vs Rated Vacuum Thrust

Figure III-4-A



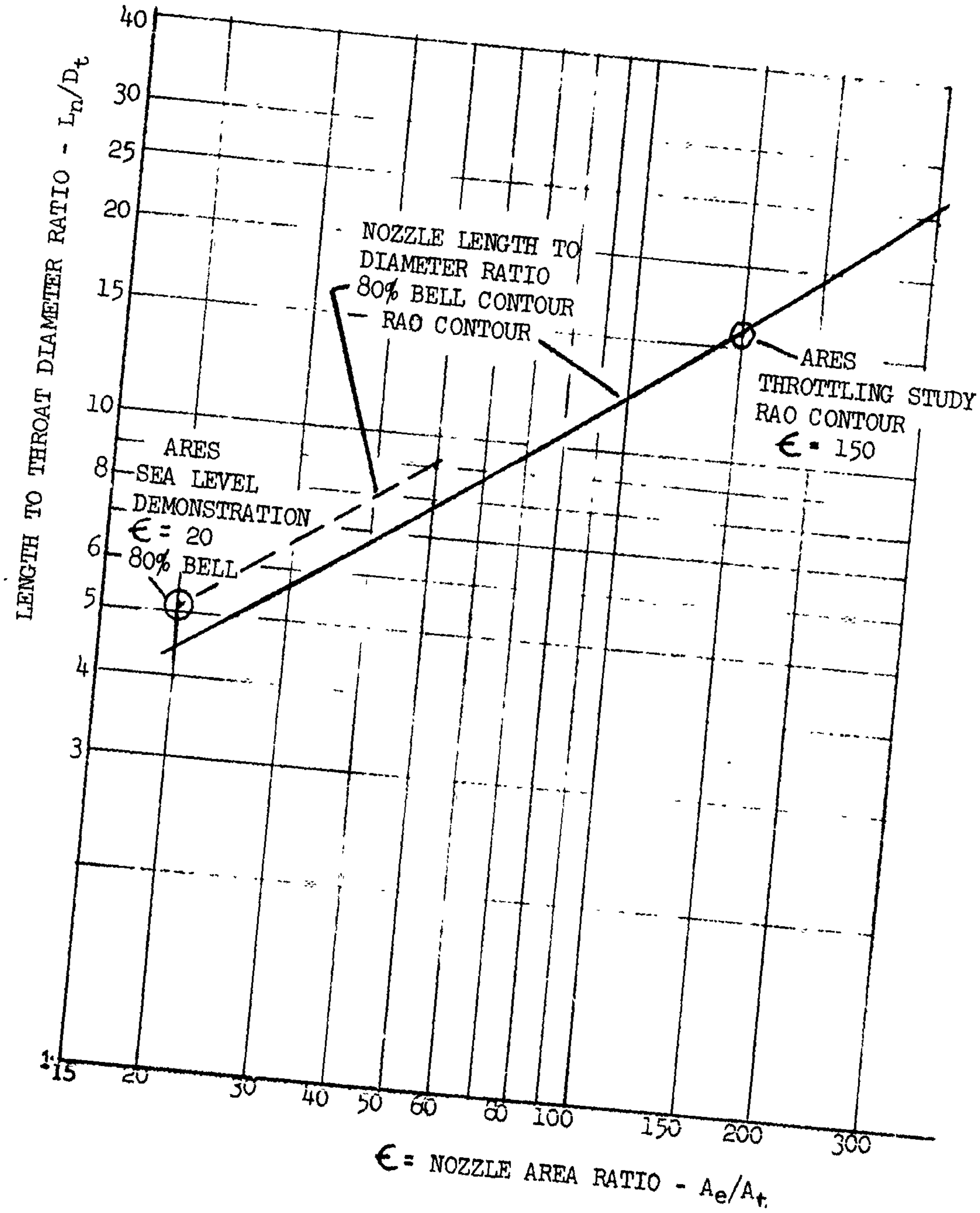
ARES Wet Weight vs Rated Vacuum Thrust

Figure III-5-A



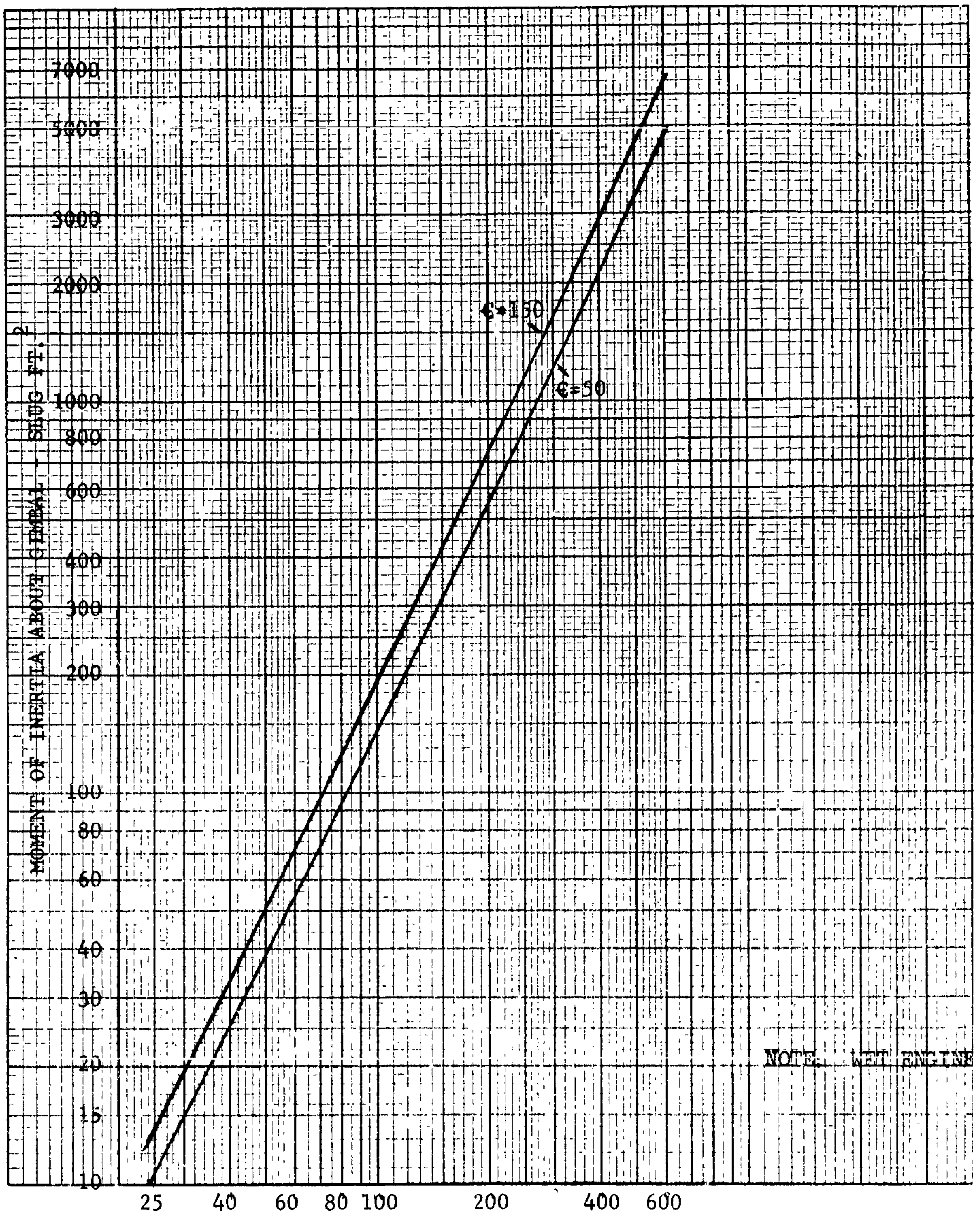
ARES Envelope Length and Outside Diameter vs Vacuum Thrust

Figure III-6-A



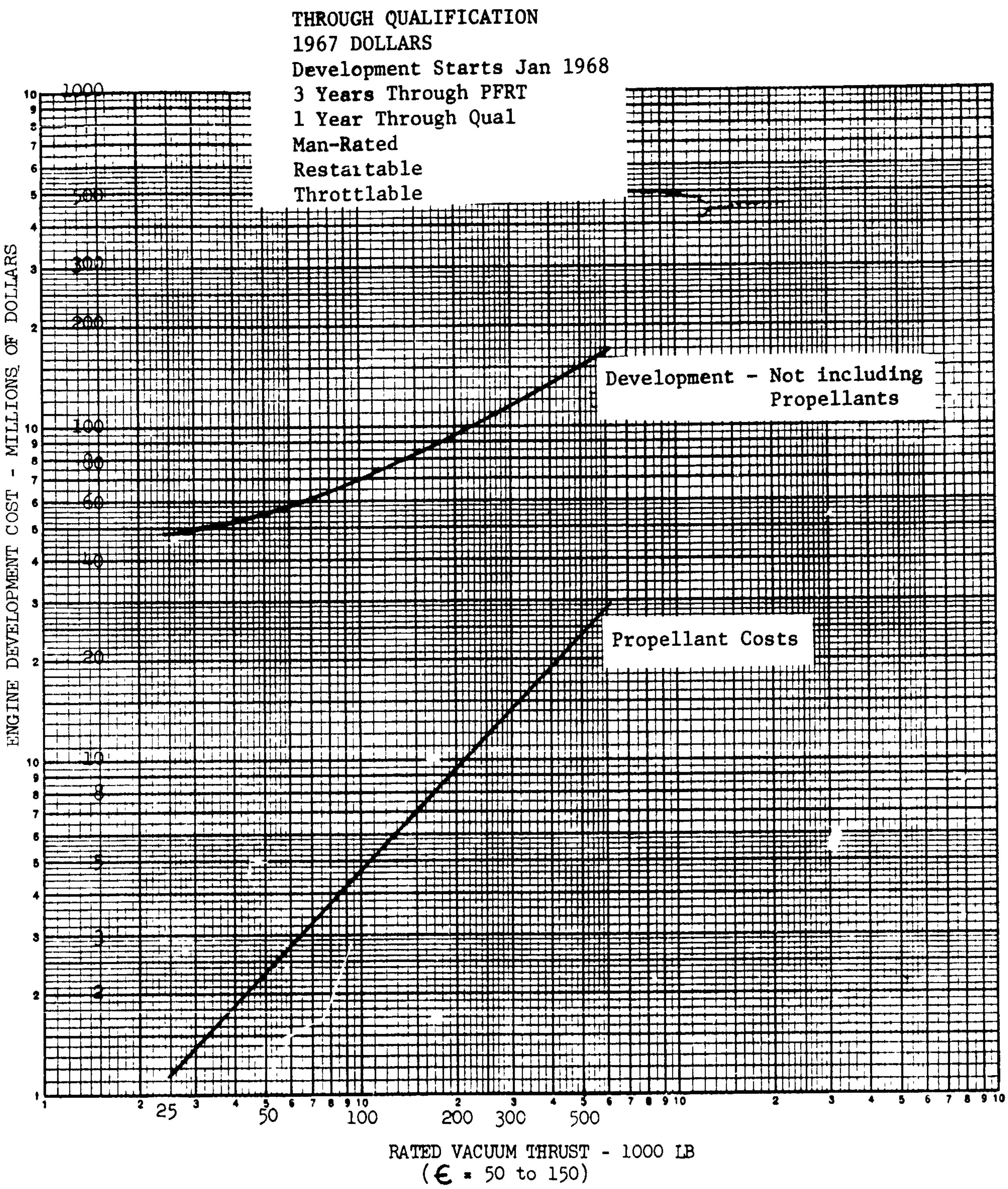
RAO and 80% Bell Nozzle Dimension Ratios

Figure III-7-A



ARES Gimbal Moment vs Vacuum Thrust

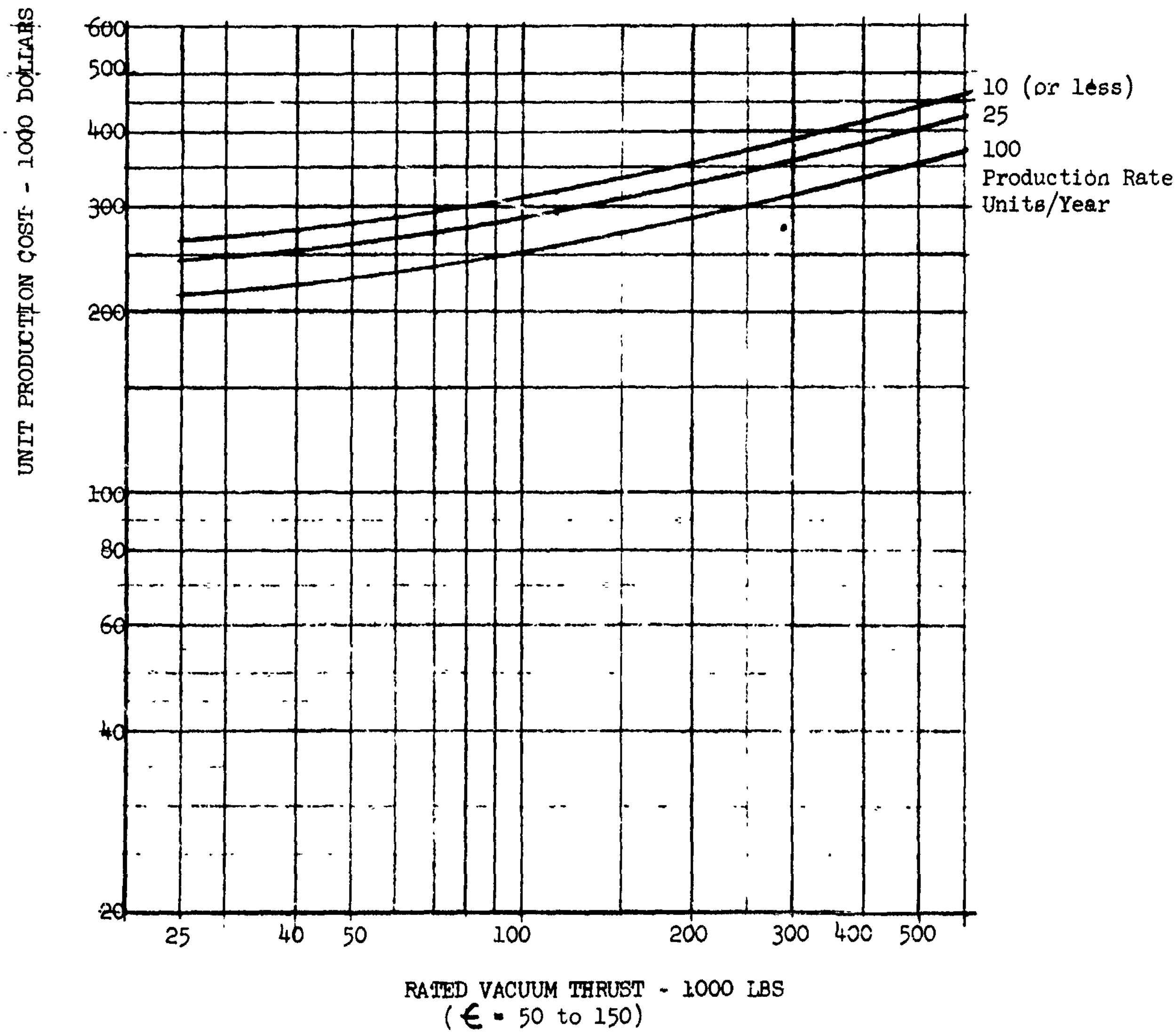
Figure III-8-A



ARES Development Cost

Figure III-9-A

1967 DOLLARS
Includes Acceptance Testing
and Support Through Launch
Man-Rated
Restartable
Throttlable
Propellant Costs Not Included



ARES Production Cost

Figure III-10-A