5105-29
Solar Thermal Power Systems Project
Parabolic Dish Systems

DOE/JPL-1060-35
Distribution Category UC-62b

Cost and Price Estimate of Brayton and Stirling Engines in Selected Production Volumes

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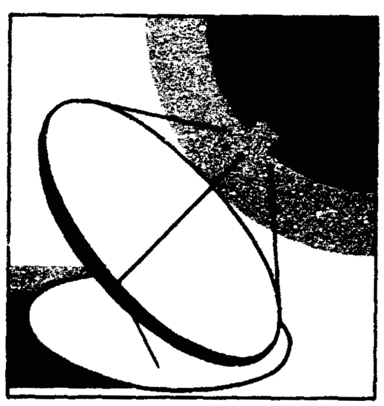

May 31, 1980

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
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Pasadena, California

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The JPL Solar Thermal Power Systems Project is sponsored by the U.S. Department of Energy and forms a part of the Solar Thermal Program to develop low-cost solar thermal and electric power plants.

ABSTRACT

This report details the methods used to determine the production costs and required selling price of Brayton and Stirling engines modified for use in solar power conversion units. The Brayton engine, designed by Garrett AiResearch Manufacturing Company, was upgraded to a 20 kW design. The Stirling 30 kW engine was designed by United Stirling of Sweden for non-solar applications.

Each engine part, component and assembly was examined and evaluated to determine the costs of its material and the method of manufacture based on specific annual production volumes. Cost estimates are presented for both the Stirling and Brayton engines in annual production volumes of 1,000, 25,000, 100,000, and 400,000. At annual production volumes above 50,000 units, the costs of both engines are similar, although the Stirling engine costs are somewhat lower.

It was concluded that modifications to both the Brayton and Stirling engine designs could reduce the estimated costs.

CONTENTS

SECTION I

INTRODUCTION

The principal objective of this study was to determine production costs and "required selling prices"* of both Brayton and Stirling engines which have been selected for use in solar energy applications. Cost and price determinations were made for annual production volumes of 1000, 25,000, 100,000 and 400,000 units. The generated numbers were used to compare the relative cost and selling price of the engines intended for use in solar power conversion units. The following engines were evaluated:

Brayton Engine - A 10 kW subatmospheric engine with a recuperator, as designed by Garrett AiResearch Manufacturing Company of California. The engine was upgraded to a 20 kW design; increases in material and labor costs were calculated by using a factor equal to the cube root of 2.00 (1.26) for the material required, as suggested by the manufacturer.

Stirling Engine - Rated at 30 kW for continuous operation, this engine designed by United Stirling in Malmo, Sweden utilizes a P-40 design modified for solar power conversion use.

Existing engine designs were evaluated. No attempt was made to modify the designs to reduce costs.

This study estimated the cost of direct labor, material and purchased parts to generate a cost number. A figure of $10.00/hour was applied for direct labor. Estimates were made of the tooling, capital equipment, and factory area required in determining the selling price of the engines.

The manufacturers of the Brayton and Stirling engines were contacted in order to obtain the detailed information (drawings, specifications, etc.) from which to make cost estimates. The manufacturers agreed to supply the necessary information, provided JPL would execute an Agreement of Confidentiality and/or a Secrecy Agreement that would preserve the proprietary rights of the companies involved. As a result, JPL cannot release detailed cost information on parts, components or assemblies. The only information that may be published is the final cost and selling price numbers of a complete engine.

Representatives from both United Stirling and Garrett AiResearch Manufacturing Company of California have reviewed and concurred with the JPL approach to the manufacturing process selected

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*"Required Selling Price" is the price that would be required to meet all costs and to make a reasonable profit. This includes direct operating costs and all indirect and financial costs (profit, taxes, etc.).

for each part, component, etc. Additionally, these representatives reviewed the cost numbers generated by JPL for direct labor and material, tooling and capital equipment.

SECTION II

METHODOLOGY

The evaluation of the Brayton and Stirling engines was performed by examining either detailed drawings, actual parts, or both, in those cases where both drawings and parts were available. The study evaluated the costs of direct labor and direct material only. Costs were determined for annual production volumes of 1000, 25,000, 100,000 and 400,000. All costs are expressed in 1979 dollars.

Each engine part, component, assembly (major and minor), and its final assembly was examined and evaluated to determine the cost of its material and the method of manufacture based on the particular annual production volume under review. In estimating the costs of engines produced at the rate of 1000/year, it was assumed that most of the items would be purchased from small shops and assembled in an in-house facility.

For production runs of 25,000 units/year, it was assumed that a make or buy decision would be made to obtain the lowest cost based on a trade-off of capital investment versus labor cost. Again, the assembly would be performed in-house. It should be noted that a production of 25.000 engines per year requires an engine be produced every four minutes based on an eight-hour working day.

As the production rate increases to 100,000 units/year, it was assumed that most items would be made in-house with the necessary investment in tooling and capital equipment. Assembly would be performed in-house. This rate would require an engine be produced every minute based on an eight-hour working day. With production at 400,000 units per year, multiple and duplicate facilities would be required which would have to operate two eight-hour working shifts per day.

For low production volumes of 1000 to 25,000 units/year, the engine manufacturing costs are considered to be labor intensive, whereas the manufacture of engines at higher production volumes would be capital intensive. This could result in lower unit costs for materials and labor. Estimates were also made for the probable cost of the tooling, the capital equipment and the factory area that would be required for each of the production volumes under consideration.

Required selling prices were determined by using a modified "Interim Price Estimation Guidelines" (IPEG) computer program which was developed by JPL for use in the Low-Cost Solar Array program.* The modified IPEG provides for indirect labor and material, factory area, amortization of tooling and capital equipment, financing, taxes, inflation, profit, etc.

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*Interim Price Estimation Guidelines: A Precursor and an Adjunct to SAMIS III, Version One, JPL Internal Document 5101-33, September 10, 1977.

Some of the assumptions which were used in the modified IPEG are listed in Table 1.

Table 1

Required Selling Price Assumptions

Financing

75% Equity - 14.5%
25% Debt - 9.0% Interest

Income Tax - 50%

Depreciation - Straight Line

Miscellaneous Costs
15% Contingency (During Construction)
10% of Operating Costs
5% of Revenues

No Sales or Shipping Costs

No R&D Amortization

Inflation Rate - 6%

Profit - Approximately 12%

SECTION III

RESULTS

The cost estimates for both the Brayton and Stirling engines in the various annual production quantities are shown in Tables 2 through 5. (Results are in 1979 dollars.) Estimated costs of Stirling engines at the lower annual production rates are substantially higher than those for Brayton engines. At annual production volumes above 50,000 units, costs of both engines are similar, although the Stirling engine costs are somewhat lower.

A curve illustrating the cost reductions obtained by increases in annual production volumes is presented in Figure 1. The costs of the Stirling engine decrease dramatically with increases in annual production volume due to reductions of both material and labor costs. Material and labor cost reductions are primarily influenced by what is called the "cold part" of this Stirling engine which is similar to an automotive internal combustion engine. Figure 2 is a bar chart illustrating the cost reductions obtained with increases in annual production volumes. Figure 3 is a bar chart showing engine costs per kW peak for each annual production volume. Figure 4 illustrates the required selling price of the engine versus annual production volume. Figure 5 is a bar chart illustrating the required selling price of the engine per kW peak versus production volumes.

Both AiResearch and United Stirling have indicated that modifications could be made to their engine designs to reduce the estimated costs.

Table 2. Engine Cost Estimate
1000 Units/Year

	BRAYTON (20 kWp)	STIRLING (30 kWp)
Raw Material and/or Purchased Parts	$ 1,430.65	$ 3,709.62
Labor Hours	31.99	135.89
Labor Cost @ $10.00/Hour	319.90	1,358.90
Miscellaneous	--	200.00
Total Engine Cost (Labor & Material)	1,750.55	5,268.52
Engine Cost/kW Peak	88.00	176.00
Capital Equipment	1,800,000.00	3,361,000.00
Tooling	1,200,000.00	2,531,500.00
Total Capital Equipment & Tooling	3,000,000.00	5,892,500.00
Capital Equipment & Tooling Cost/Unit	3,000.00	5,893.00

Table 3. Engine Cost Estimate
25,000 Units/Year

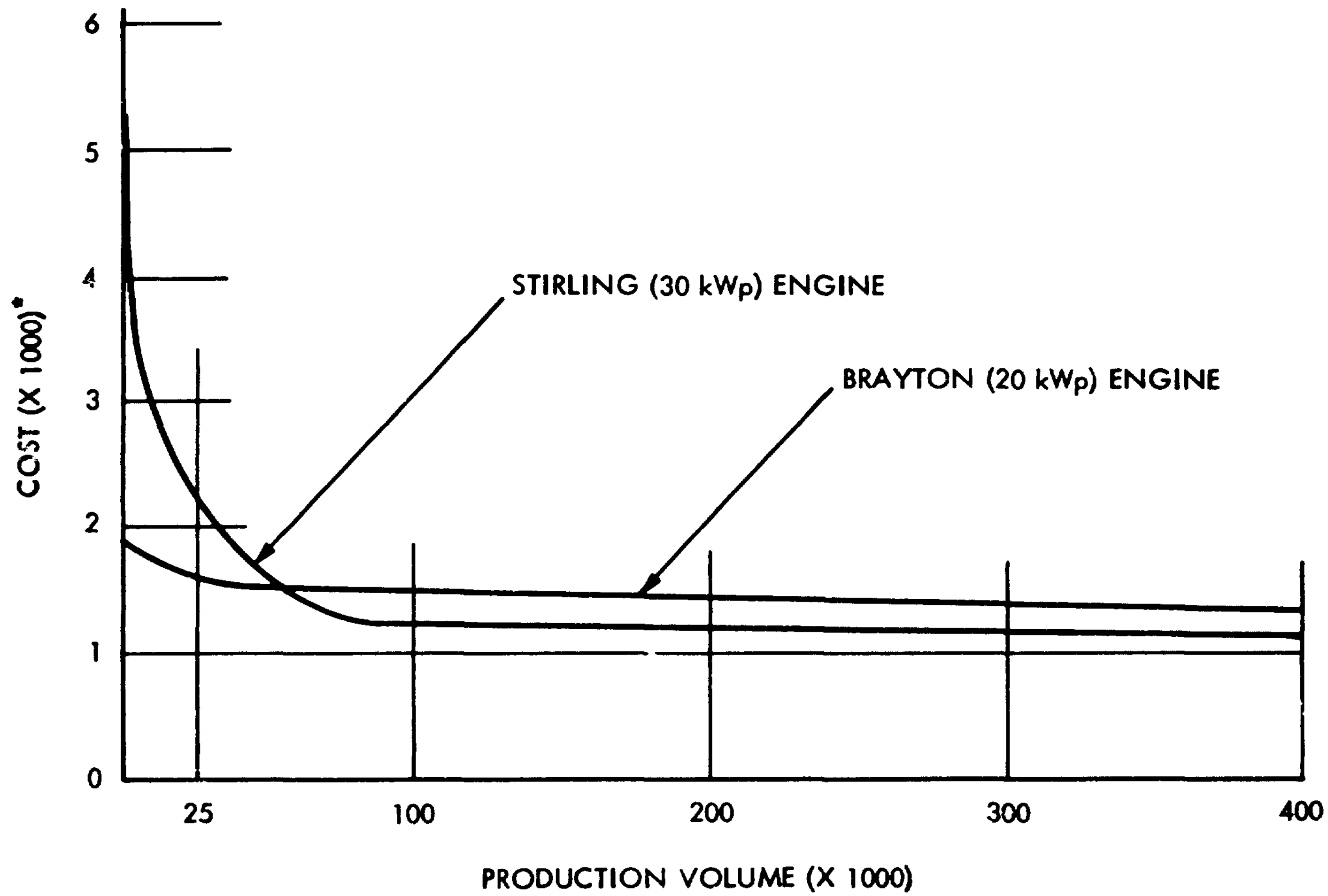
	BRAYTON (20 kWp)	STIRLING (30 kWp)
Raw Material and/or Purchased Parts	$ 1,382.74	$ 1,662.11
Labor Hours	21.88	42.14
Labor Cost @ $10.00/Hour	218.80	421.40
Miscellaneous	--	125.00
Total Engine Cost (Labor & Material)	1,601.54	2,208.51
Engine Cost/kW Peak	80.00	74.00
Capital Equipment	3,427,950.00	28,600,000.00
Tooling	3,189,165.00	9,573,000.00
Total Capital Equipment & Tooling	6,617,115.00	38,173,000.00
Capital Equipment & Tooling Cost/Unit	265.00	1,527.00

Table 4. Engine Cost Estimate
100,000 Units/Year

	BRAYTON (20 kWp)	STIRLING (30 kWp)
Raw Material and/or Purchased Parts	$ 1,317.78	$ 1,055.77
Labor Hours	12.53	12.12
Labor Cost @ $10.00/Hour	125.30	121.20
Miscellaneous	--	30.00
Total Engine Cost (Labor & Material)	1,504.08	1,206.97
Engine Cost/kW Peak	75.00	40.00
Capital Equipment	20,775,575.00	70,565,000.00
Tooling	9,081,800.00	22,229,000.00
Total Capital Equipment & Tooling	29,857,375.00	92,794,000.00
Capital Equipment & Tooling Cost/Unit	299.00	928.00

Table 5. Engine Cost Estimate
400,000 Units/Year

	BRAYTON (20 kWp)	STIRLING (30 kWp)
Raw Material and/or Purchased Parts	$ 1,271.24	$ 1,010.61
Labor Hours	9.49	9.67
Labor Cost @ $10.00/Hour	94.90	96.70
Miscellaneous	--	25.00
Total Engine Cost (Labor & Material)	1,366.14	1,132.31
Engine Cost/kW Peak	68.00	38.00
Capital Equipment	54,694,000.00	187,635,000.00
Tooling	24,057,800.00	75,695,000.00
Total Capital Equipment & Tooling	78,751,800.00	263,330,000.00
Capital Equipment & Tooling Cost/Unit	197.00	658.00



* 1979 DOLLARS

Figure 1. Engine Cost versus Annual Production Volume

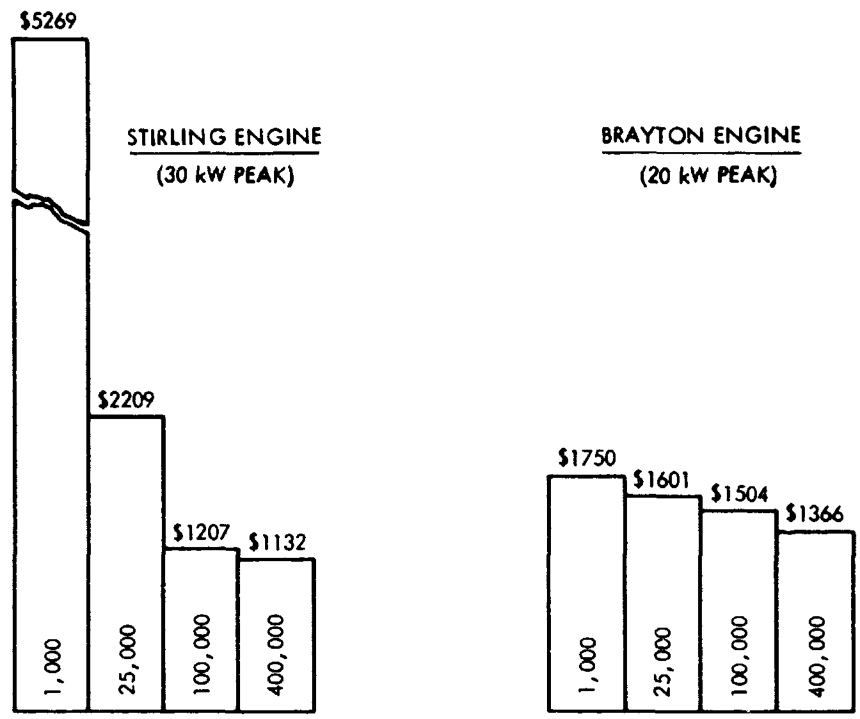


Figure 2. Engine Cost versus Annual Volume

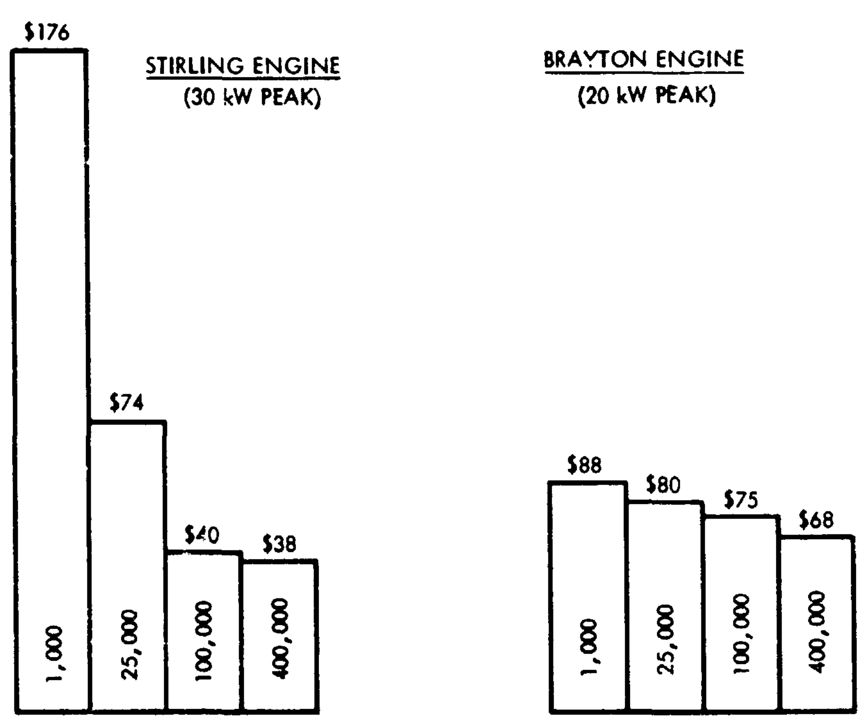


Figure 3. Engine Cost per kW Peak versus Annual Volume

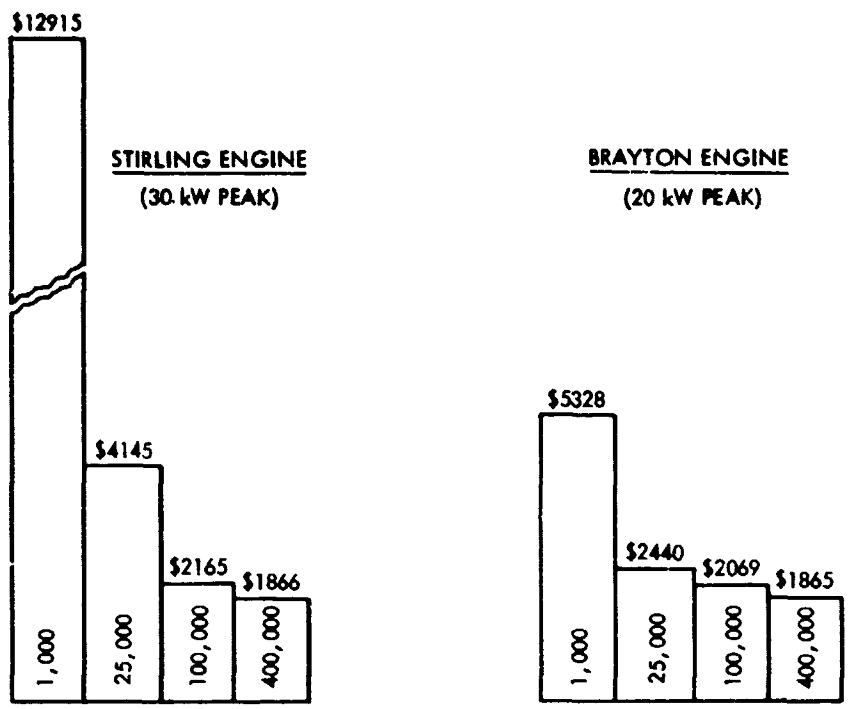


Figure 4. Engine Price versus Annual Volume

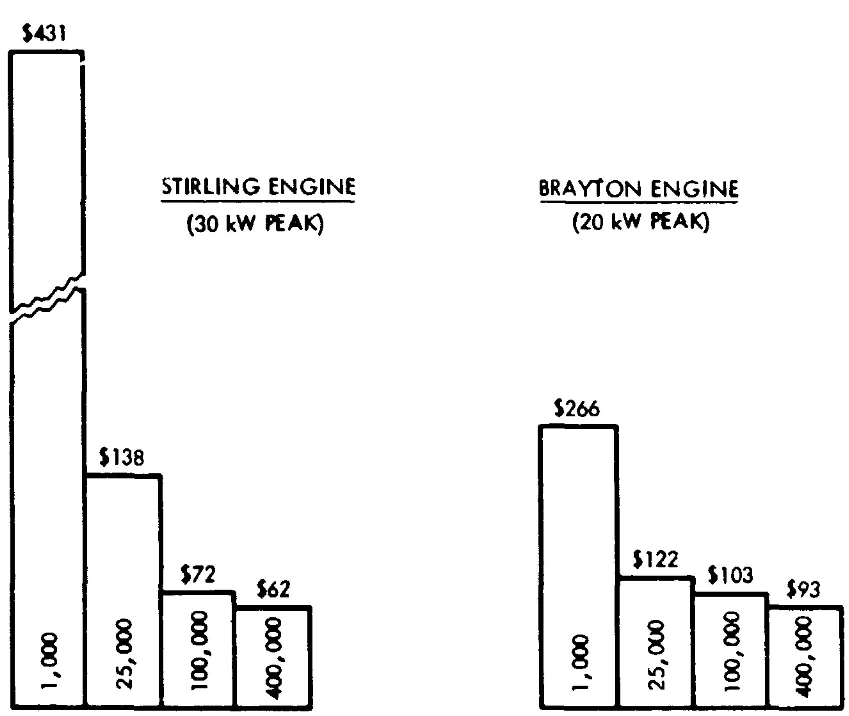


Figure 5. Engine Price per kW Peak versus Annual Volume