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USAAVLABS TECHNICAL REPORT 68-59

TURBINE ENGINE AND TURBINE ENGINE COMPONENT COST

By

David B. Cale

July 1968

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

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Final Report

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David B. Cale

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SUMMARY

It is anticipated that cost reduction will become an increasingly important factor in the future of the gas turbine engine. Therefore, it is considered to be necessary to establish a research program aimed at gas turbine engine cost reduction. The objectives of this program were to identify high-cost engine components and to examine the changes in their cost with increasing production. Cost data were solicited from all major gas turbine engine manufacturers relative to total engine cost and major component cost at various engine production levels. The data indicate that the compressor, turbine, and accessories are the highest cost components and that they represent, on the average, 88 percent of the total engine cost. Results also indicate that the accessories experience less cost reduction with increasing production than do any other engine components. In the compressor and turbine area, the most promising means of cost reduction appears to be simply reduction of the number of stages through advances in compressor and turbine technology. The results of this program further indicate the need for a more detailed study in the compressor, turbine, and accessory areas.

FOREWORD

This work was performed by the Propulsion Division of the U. S. Army Aviation Materiel Laboratories (USAAVLABS) under House Task PP 66-44.

Acknowledgment is given to the numerous engine manufacturers who responded to the requests for cost data. Acknowledgment is also given to Mr. Paul Chesser of the Propulsion Division, USAAVLABS, who was instrumental in gathering the data on which this report is based.

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STATEMENT OF PROBLEM

It is anticipated that the future of the gas turbine engine will depend on reduction in engine cost as well as on advancements in engine technology. Therefore, it is considered to be necessary to establish a research program aimed at gas turbine engine cost reduction. However, before a realistic program can be established in this area, it is necessary to identify the high-cost items and to define the cost sensitivity of the various components relative to fabrication and inspection requirements, rejection rates, learning curves, etc. The objectives of this study are to identify high-cost components and to examine changes in their cost as a function of their production level.

APPROACH TO PROBLEM

Cost data were solicited from all major gas turbine engine manufacturers relative to total engine cost and the cost of all major components, including material, machining, fabrication, inspection, parts rejection, etc., at approximately the 200th, 500th, and 1000th production unit. Also included in the requested data were all purchased parts and outside produced items costing in excess of $50.

It should be noted that the term "cost" in this report refers only to manufacturing cost, not delivered price. Cost does not include profit, engineering support, special tools, shipping container, G&A, IR&D, CE, etc.

Two cost breakdowns were furnished for each engine at each production level. The first breaks down total engine cost into material, labor, and overhead. The second breaks down the cost into five major component groups as follows:

1. Compressor
2. Combustor
3. Turbine
4. Accessory Drive
5. Fuel, Air, Lube, and Electrical Systems

From these data, an attempt was made to identify the high-cost items and those items which do not seem to follow a normal learning curve. The sample selected for this study from the cost data received was made up totally of turboshaft engines. There are a number of reasons for thus restricting the sample. They are as follows:

1. More cost data were submitted for shaft-type engines.

2. The majority of the Army's gas turbine engines are shaft-type engines.

3. With the exception of afterburners, variable exhaust nozzles, and fan stages, all gas turbine engine components are found in the turboshaft engine; therefore, any successful cost-reduction program relative to the shaft-type engine will be directly applicable to other gas turbine engine types.

RESULTS AND DISCUSSION

The overall response by the engine manufacturers to the request for data was, in general, very good. Although some of the data submitted was lacking in detail, only one negative reply was received. However, it should be realized that even though the response was good, the results and conclusions contained herein are based on a data sample that is, statistically speaking, relatively small and lacking in detail; as such, it should be treated with caution. The available information represents an overall cost breakdown; however, specific details of cost contributions relative to individual parts or to manufacturing cost, scrappage, inspection, etc., are not available at the present time.

HIGH-COST COMPONENTS

It may be seen from Table I and Figures 1, 2, and 3 that the compressor, turbine, and accessories (fuel, air, lube, and electrical systems) are the predominant high-cost items in the engine, while the combustor and accessory drive are of less significance from a cost standpoint. The table

TABLE I. COMPONENT COST AS A PERCENTAGE OF TOTAL ENGINE COST

	Engine				
Component	A (pct)	B (pct)	C (pct)	D (pct)	Avg (pct)
200th Unit					
Compressor	37.0	31.5	24.2	36.3	32.25
Combustor	10.8	7.05	6.9	2.65	6.85
Turbine	23.9	29.4	26.4	35.8	28.9
Accessory Drive	7.4	6.95	2.9	5.05	5.6
Accessories	20.9	25.1	39.6	20.2	26.45
500th Unit					
Compressor	36.6	31.4	23.7	31.8	30.9
Combustor	10.35	6.9	6.7	2.7	6.7
Turbine	24.5	29.9	26.4	37.7	29.6
Accessory Drive	6.55	6.7	2.9	4.5	5.2
Accessories	22.0	25.1	40.3	23.3	27.7
1000th Unit					
Compressor	37.3	30.6	23.6	29.6	30.3
Combustor	8.2	7.0	6.6	3.13	6.2
Turbine	24.9	30.0	26.6	36.4	29.5
Accessory Drive	6.4	7.05	2.9	4.92	5.3
Accessories	23.2	25.35	40.4	25.95	28.7

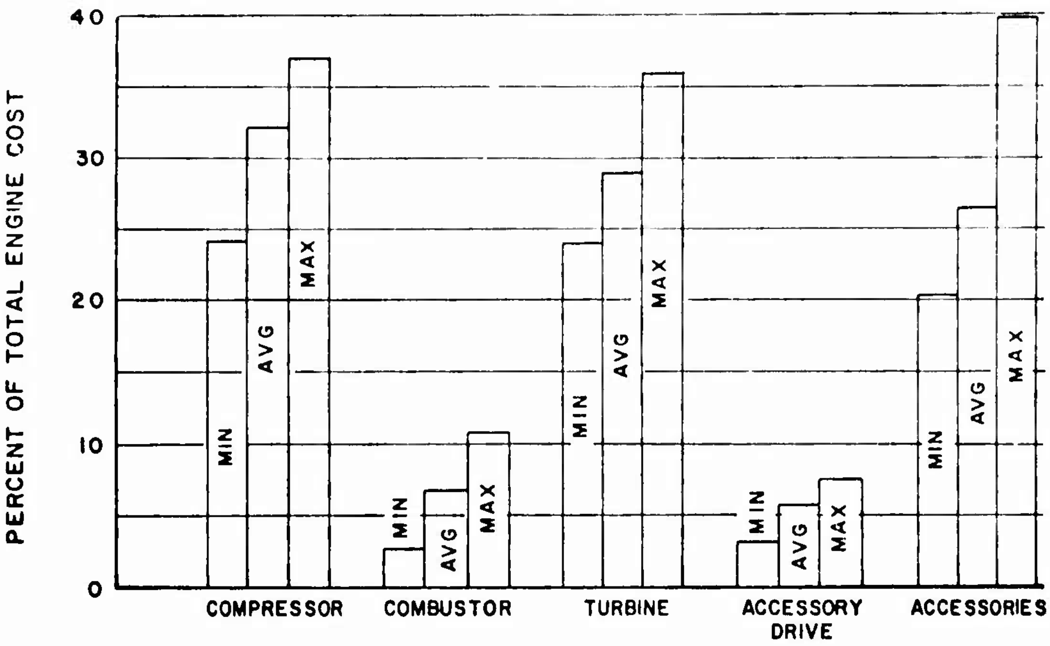

Figure 1. Component Cost in Percentage of Total Engine Cost at the 200th Unit.

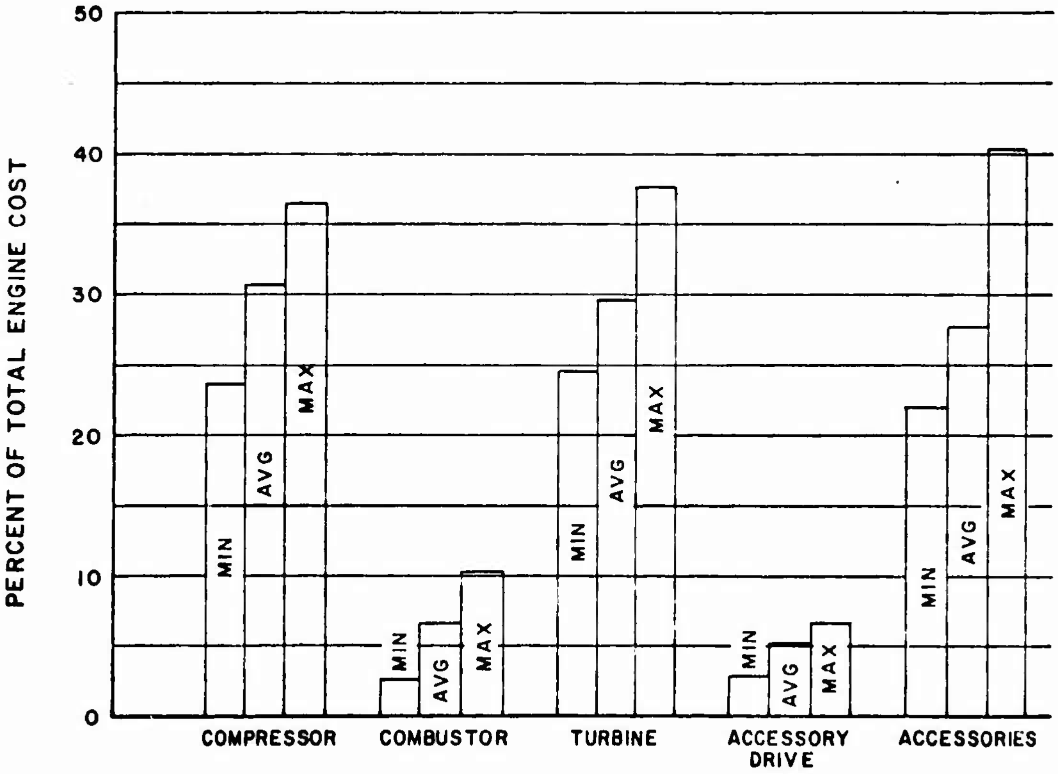

Figure 2. Component Cost in Percentage of Total Engine Cost at the 500th Unit.

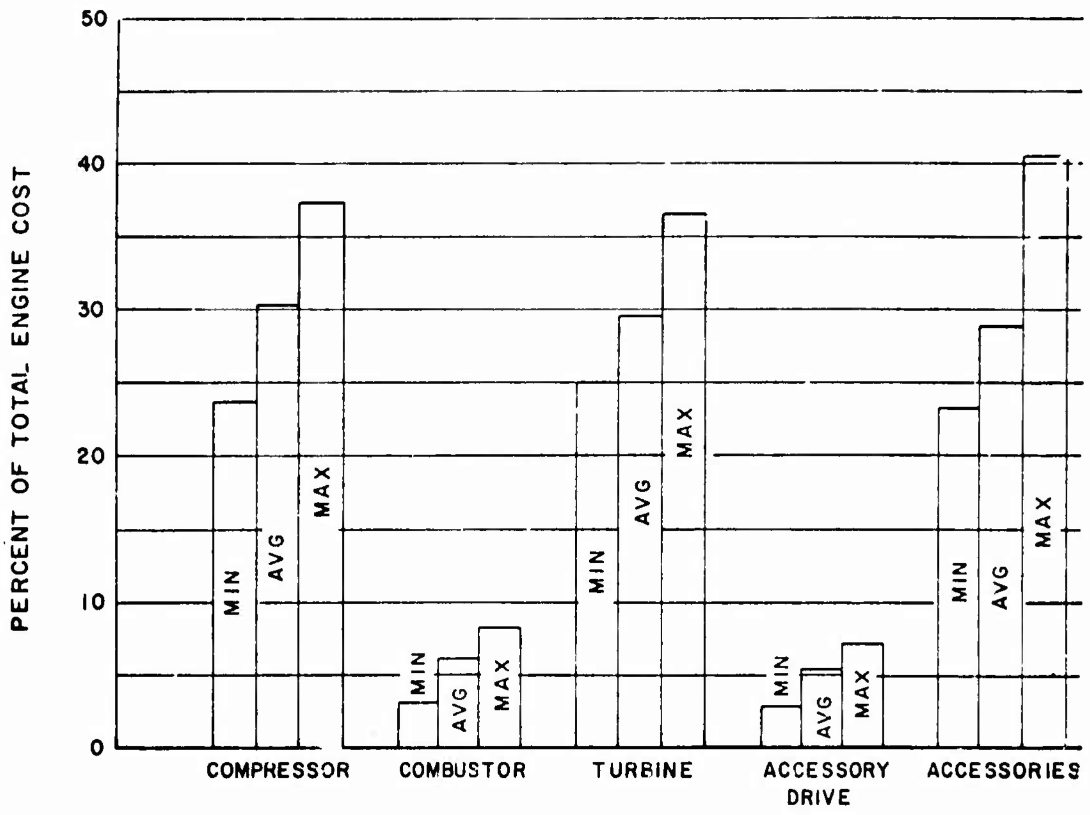

Figure 3. Component Cost In Percentage of Total Engine Cost at the 1000th Unit.

and figures also show that the percentage of total engine cost represented by these components does not change significantly with production level. The compressor, turbine, and accessories represent, on the average, 31.15, 29.3, and 27.6 percent, respectively, of the total engine cost. The remaining 11.95 percent is contributed by the combustor (6.58) and the accessory drive system (5.37). An average engine cost breakdown, considering all engines and all production levels, is shown in Figure 4. It would appear from the above that if significant engine cost reductions are to be achieved, they must come from the compressor, turbine, or accessory area. A more detailed discussion of each major component area follows.

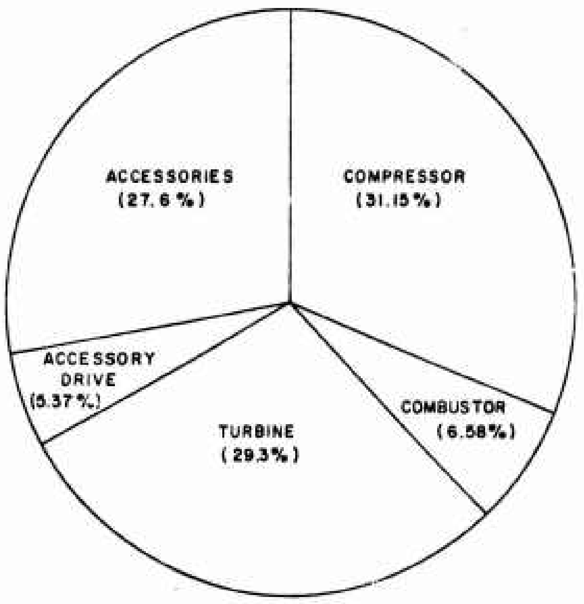

Figure 4. Average Breakdown of Engine Cost Into Component Costs.

COMPRESSOR

The compressor is, on the average, the highest cost component in the engine. Table I and Figures 1 through 4 show that the compressor cost ranges from 23.6 to 37.3 percent of total engine cost, with an average of 31.15 percent. From the data gathered, the compressor cost does not appear to be a function of engine power. The data indicate that the increase in compressor cost between the smallest engine studied and the largest is only 9 percent, while the increase in horsepower is approximately 280 percent. It appears that compressor cost is influenced by two main factors: first, compressor type (centrifugal, axial-centrifugal, or axial) and, second, the number of stages. Indications are that the centrifugal compressor is the most expensive, followed by the axial-centrifugal and the all-axial, in that order.

Compared to the overall engine learning curve (Figure 5), the compressor learning curve (Figure 6) indicates a greater percentage of cost reduction, due to increased production, for the compressor than for the engine as a whole. The data used in the construction of Figures 5 and 6 as well as Figures 7 through 10 are shown in Table II. The data also seem to indicate that the all-axial units achieve greater cost reduction with increased production than do the axial-centrifugal units. In Figure 6, the all-axial compressors make up the lower portion of the curve, while the axial-centrifugal compressors fall near the upper limit of the range. This seems to indicate that axial blades and vanes lend themselves more readily

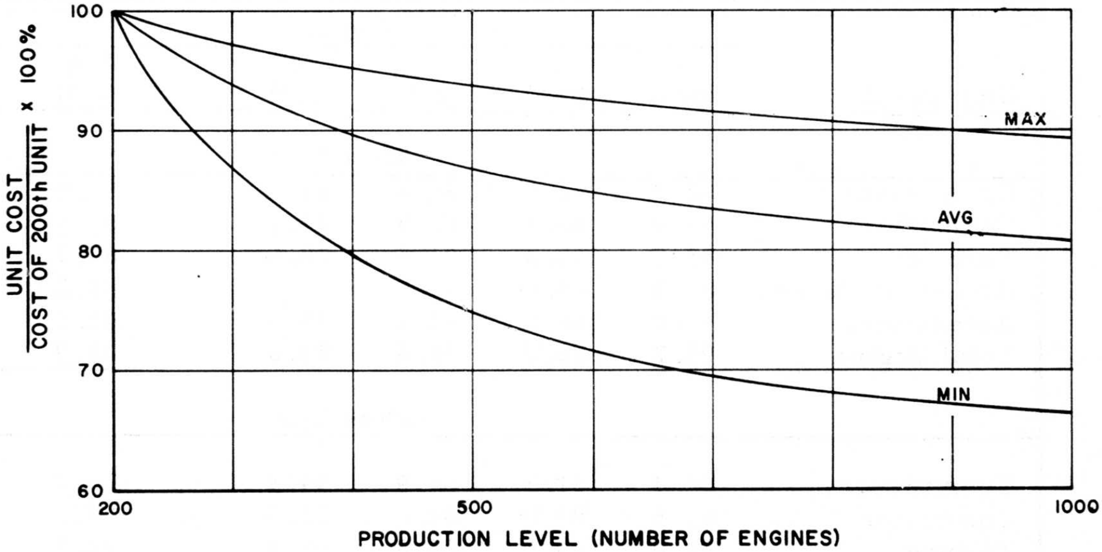

Figure 5. Overall Engine Learning Curve.

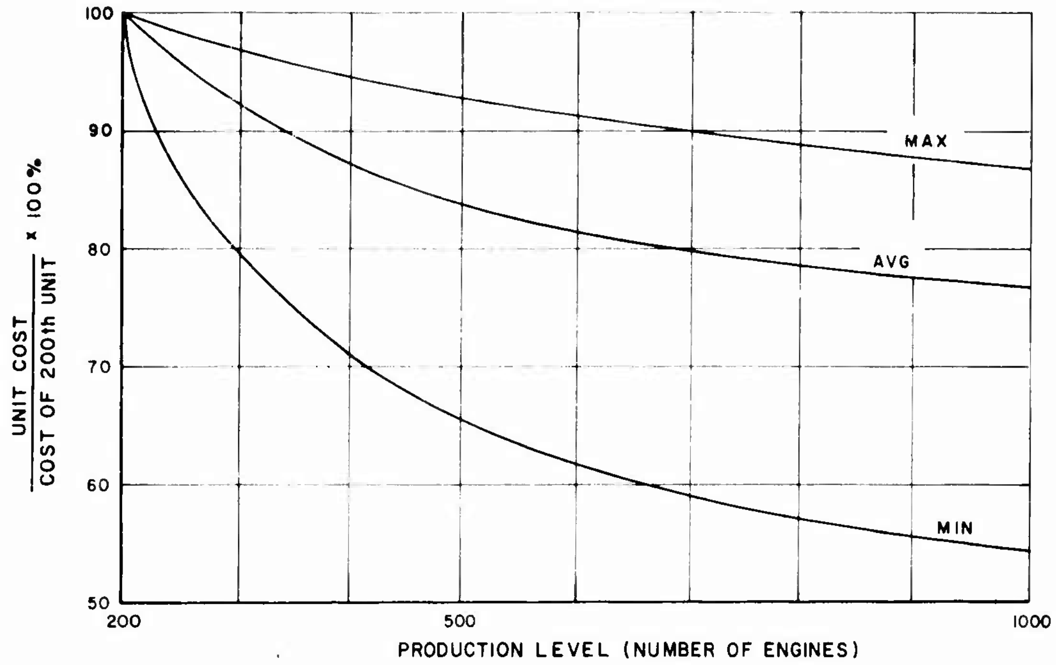

Figure 6. Compressor Learning Curve.

TABLE II. COMPONENT AND ENGINE COSTS AT THE 500TH AND 1000TH UNIT AS A PERCENTAGE OF THE 200TH UNIT COST

	Engine				
Component	A (pct)	B (pct)	C (pct)	D (pct)	Avg (pct)
			500th Unit		
Compressor	92.7	87.9	89.4	65.5	83.9
Combustor	89.9	85.9	88.5	74.9	84.8
Turbine	95.9	90.3	91.5	78.6	89.1
Accessory Drive	82.3	84.9	91.1	66.4	81.2
Accessories	99.0	87.8	93.1	86.0	91.5
Total Engine	93.7	88.0	91.4	74.6	86.9
			1000th Unit		
Compressor	84.4	81.3	86.9	54.3	76.7
Combustor	63.5	83.0	84.6	77.3	77.1
Turbine	87.0	85.9	89.8	67.4	82.5
Accessory Drive	71.9	85.3	88.5	64.5	77.6
Accessories	93.2	84.6	91.0	85.0	88.5
Total Engine	83.7	83.7	89.2	66.3	80.7

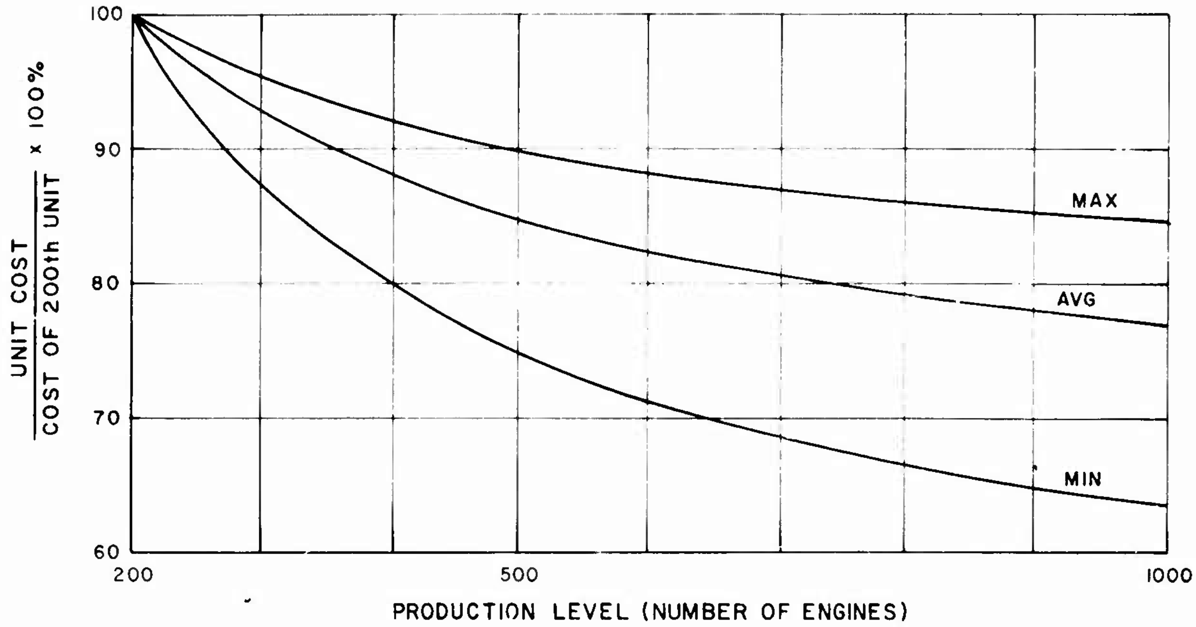

Figure 7. Combustor Learning Curve.

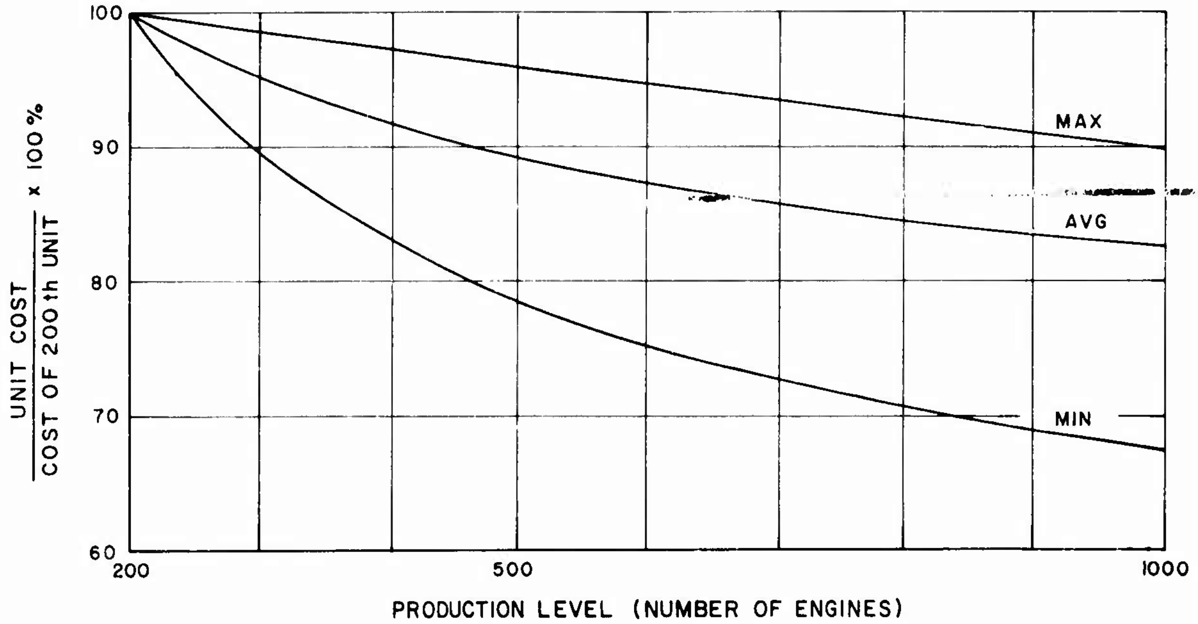

Figure 8. Turbine Learning Curve.

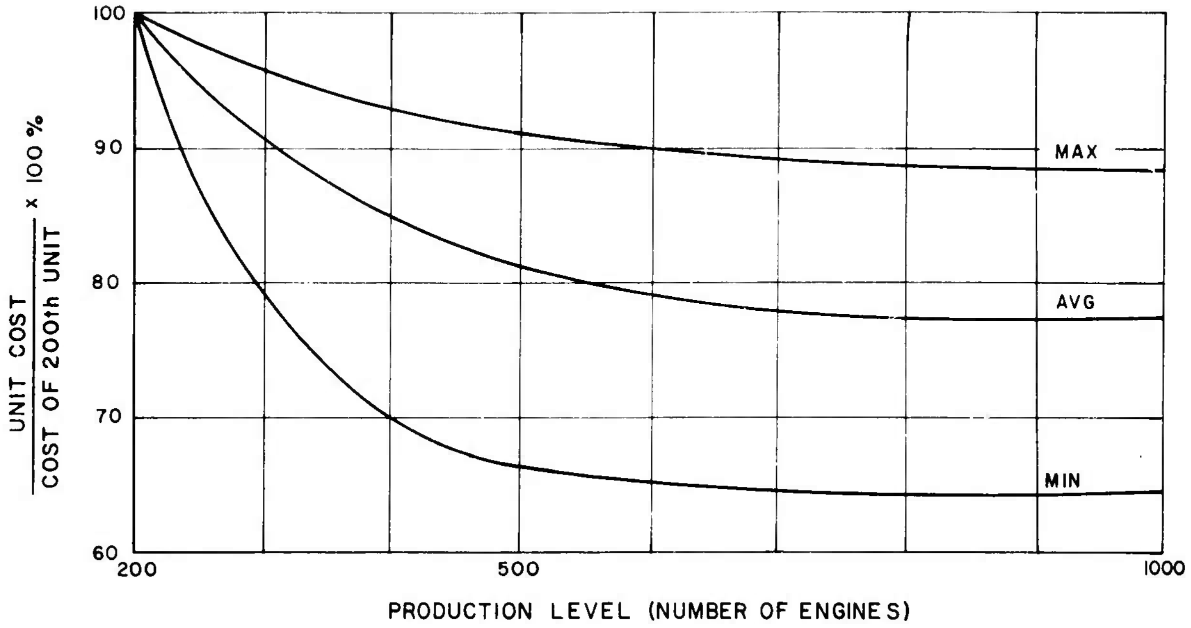

Figure 9. Accessory Drive Learning Curve.

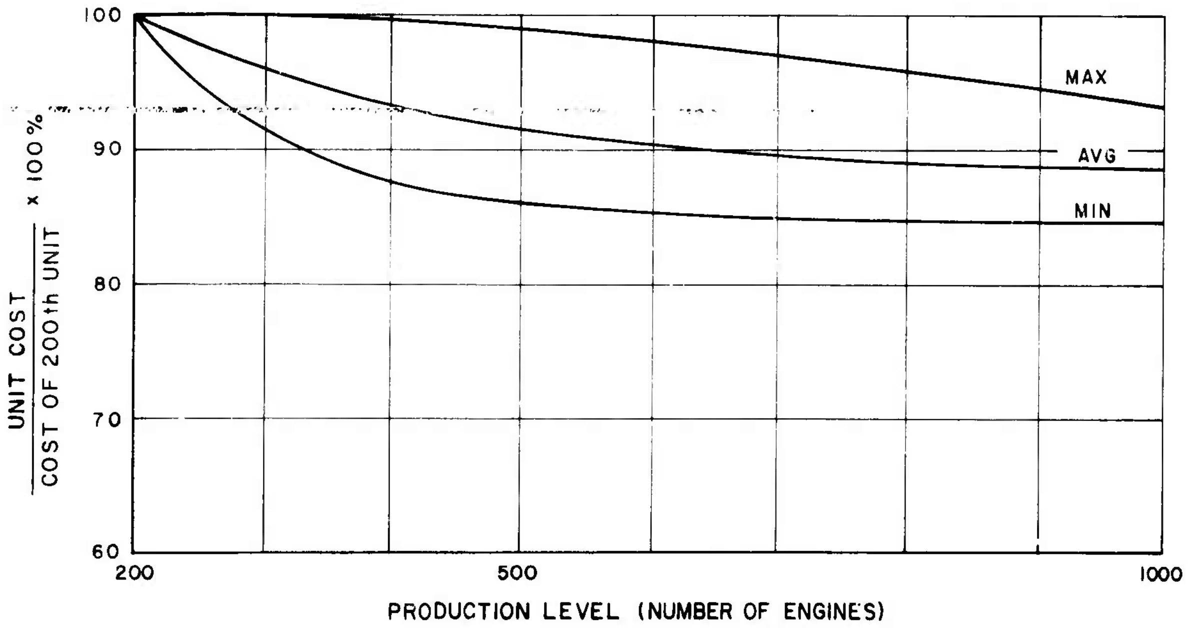

Figure 10. Accessories Learning Curve.

to mass production techniques than to centrifugal impellers and diffusers. This is not surprising when we consider the fabrication techniques required for the two types of compressors. Here, again, a word of caution should be inserted. Due to the relatively small size of the sample studied, differences between manufacturers may be a significant factor in this observed difference.

The second factor affecting compressor cost, the number of stages, is influenced by the engine pressure ratio and by the technology level of the compressor. As engine pressure ratios are increased in an effort to improve specific fuel consumption, the number of compressor stages required and the compressor cost will also increase. On the other hand, as compressor technology advances, the pressure ratio attainable from each stage increases, and the number of stages required and, therefore, the compressor cost will decrease. Therefore, advances in compressor technology may well be instrumental in reducing compressor cost.

COMBUSTOR

As with the compressor, combustor cost does not appear to be a function of engine horsepower. The combustor represents a relatively small fraction of the total engine cost, with a range of from 2.65 to 10.8 percent. The average combustor cost was approximately 6.58 percent of the total engine cost. The data also show that the reduction in cost with increased production is greater for the combustor than for the engine as a whole (Figure 7). The combustor does not appear to lend itself to a further significant improvement in cost. It should also be noted that even if the combustor cost could be reduced by as much as 50 percent, the resulting decrease in total engine cost would be only 3.25 percent. This is not to imply that the combustor cost should be ignored. The cost of any component can become unreasonable if this cost is not considered during the design and production of the component. The point to be made here is that specific, intensive cost-reduction programs in the combustor area do not appear to be worthwhile.

TURBINE

The turbine represents one of the highest cost items in the engine, with costs ranging from 23.9 to 37.7 percent of total engine cost. Average turbine cost is 29.3 percent of total engine cost. In general, the turbine cost increases with increasing engine horsepower. The cost-reduction learning curve for the turbine is basically the same as the learning curve for the overall engine. (See Figure 8.)

It should be noted that of the turbines studied, only one had a cooled nozzle, and none had cooled blades. Preliminary studies indicate that the cost of the nozzles would be multiplied by from 1.1 to as much as 2.6, due to cooling, depending on the cooling scheme used. These studies also indicate a multiplication of from 2.6 to as much as 4.2 of turbine blade cost with the introduction of cooling. As turbine inlet temperatures are increased in advanced engines to improve specific horsepower and specific fuel consumption, cooling will be required in an increasing number of turbine blade rows, and the turbine cost will increase accordingly. It is conceivable that, in an advanced high-temperature engine, requiring cooling of two complete turbine stages, the turbine cost could easily account for as much as 45 percent of the total engine cost.

Like the compressor cost, the turbine cost is a function of the number of stages. Advanced engines, with their higher specific horsepower, will require an increasing number of turbine stages to extract the work. At the same time, advances in turbine technology will increase the work extraction per stage and, therefore, will reduce the required number of stages for a given engine. In the turbine, as in the compressor, advances in component technology are likely to become a key factor in reducing component cost. Another key factor will be the development of less expensive cooling methods or less expensive fabrication techniques for cooled blades and vanes.

ACCESSORY DRIVE

The accessory drive system, like the combustor, represents a relatively small fraction of the total engine cost, with a range of from 2.9 to 7.4 percent with an average of 5.37 percent. Also like the combustor, the reduction in cost with increased production is greater for the accessory drive than for the engine as a whole (Figure 9). It should be noted that cost reduction in the accessory drive area has a relatively insignificant effect on overall engine cost. A 50-percent reduction in the cost of the accessory drive section would result in only a 2.69-percent reduction in total engine cost.

ACCESSORIES

This group of components represents from 20.2 to 40.4 percent of the total engine cost and averages 27.6 percent. The major portion of this cost is contributed by the fuel control. This item can easily represent 65 percent of the accessory cost or 16 percent of the total engine cost. Another 15 to 20 percent of the accessories cost is made up of fuel and lube pumps and associated filters. The remaining 15 to 20 percent of the accessory system cost is made up of numerous lesser value components.

Cost reduction due to increased production is significantly less (12-percent reduction from the 200th unit to the 1000th unit) for this component group than for any other component in the engine (Figure 10). There are a number of possible explanations for this lack of cost reduction. The majority of the components which make up this group are purchased as complete assemblies from outside vendors. Therefore, the engine manufacturer does not have sufficient control over the production of these components to initiate specific cost-reduction programs. It is also possible that vendors take early orders at little or no profit in order to receive the contract, and the increased profit applied to later orders prevents significant cost reduction. In addition, in some parts (pumps, for example), similarity to other items manufactured by the vendor indicates that the part is far out on the learning curve, beyond which very little progress can be expected.

It is worthwhile at this point to examine the accessory drive and the accessories combined. The cost of this total system averages 32.97 percent of the total engine cost, with a range of from 25.25 to 43.3 percent. When the total system is considered as a package, cost-reduction possibilities that were not readily apparent from a study of the individual components are evident. If accessories could be driven at higher speeds, at or near engine speed, the need for, and therefore the cost of, reduction gears in the accessory drive could be reduced and perhaps eliminated. Although the increase in accessory speed may result in a decrease in the efficiency of the driven accessories, the overall impact on engine performance would not be significant, and the resulting cost of the accessory drive would be substantially reduced.

MATERIAL, LABOR, AND OVERHEAD COSTS

The breakdown of engine cost into material, labor, and overhead does not provide any conclusive information. The data resulting from this cost breakdown are shown in Table III and in Figures 11, 12, and 13. Figure 14 shows that, on the average, material, labor, and overhead represent 59, 12, and 29 percent, respectively, of the total engine cost. However, the range of values from which these averages were obtained is quite broad, as shown in Figures 11, 12, and 13 and Table III. The only significant difference among Figures 11, 12, and 13 is the slight narrowing of the range between maximum and minimum percentage cost for the three categories with increased production. The average percentage cost

TABLE III. MATERIAL, LABOR, AND OVERHEAD COSTS AS A PERCENTAGE OF TOTAL ENGINE COST

	Engine				
	A (pct)	B (pct)	C (pct)	D (pct)	Avg (pct)
			200th Unit		
Material	32.6	62.0	75.2	54.6	56.1
Labor	21.1	12.2	5.7	12.1	12.8
Overhead	46.3	25.8	19.1	33.3	31.1
			500th Unit		
Material	39.2	67.8	73.4	63.5	61.0
Labor	19.6	10.7	6.4	9.6	11.6
Overhead	41.2	21.5	20.2	26.9	27.4
			1000th Unit		
Material	41.9	70.3	69.2	58.1	59.9
Labor	18.3	10.4	6.8	11.5	11.7
Overhead	39.8	19.3	24.0	30.4	28.4

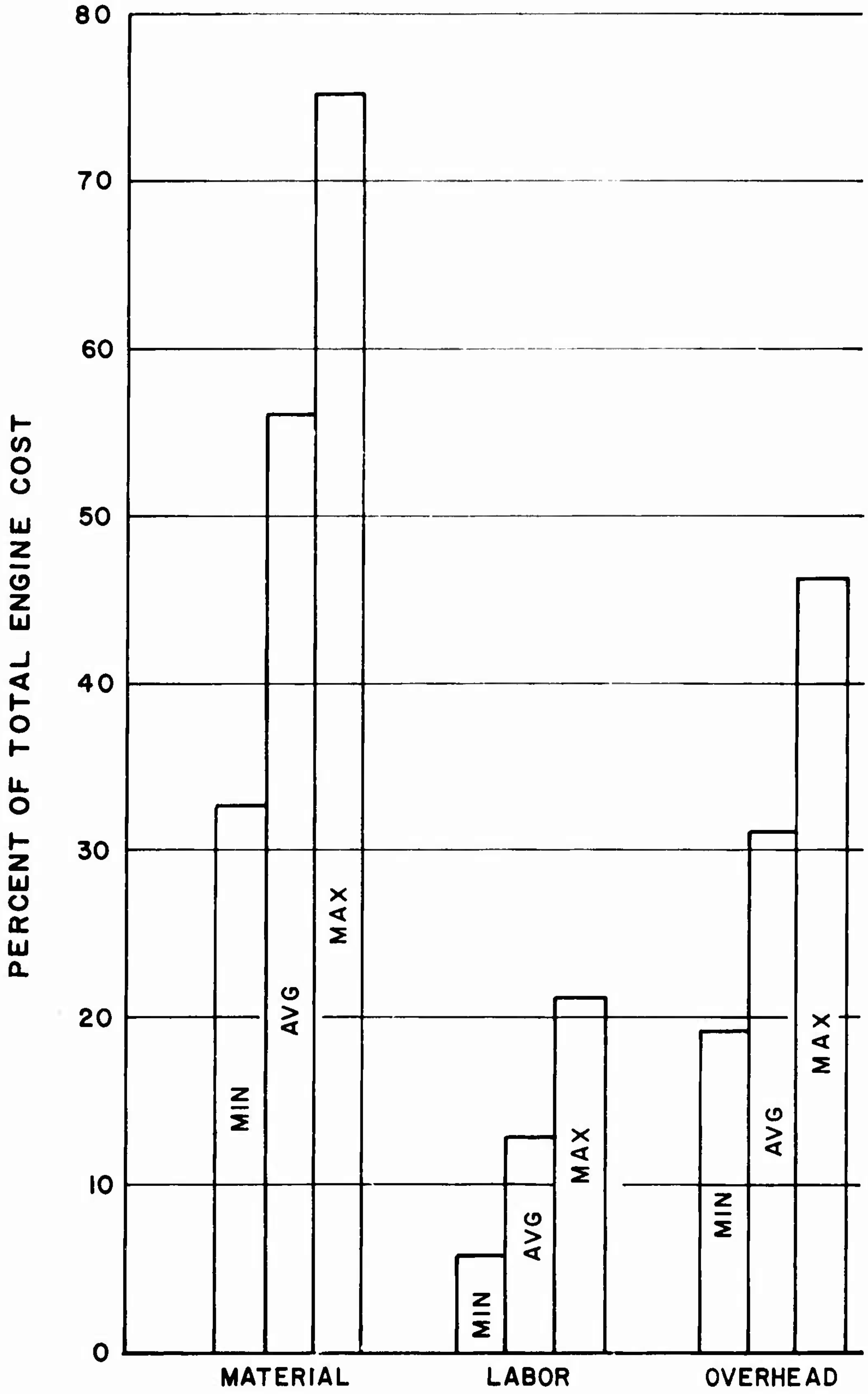

Figure 11. Material, Labor, and Overhead Costs in Percentage of Total Engine Cost at the 200th Unit.

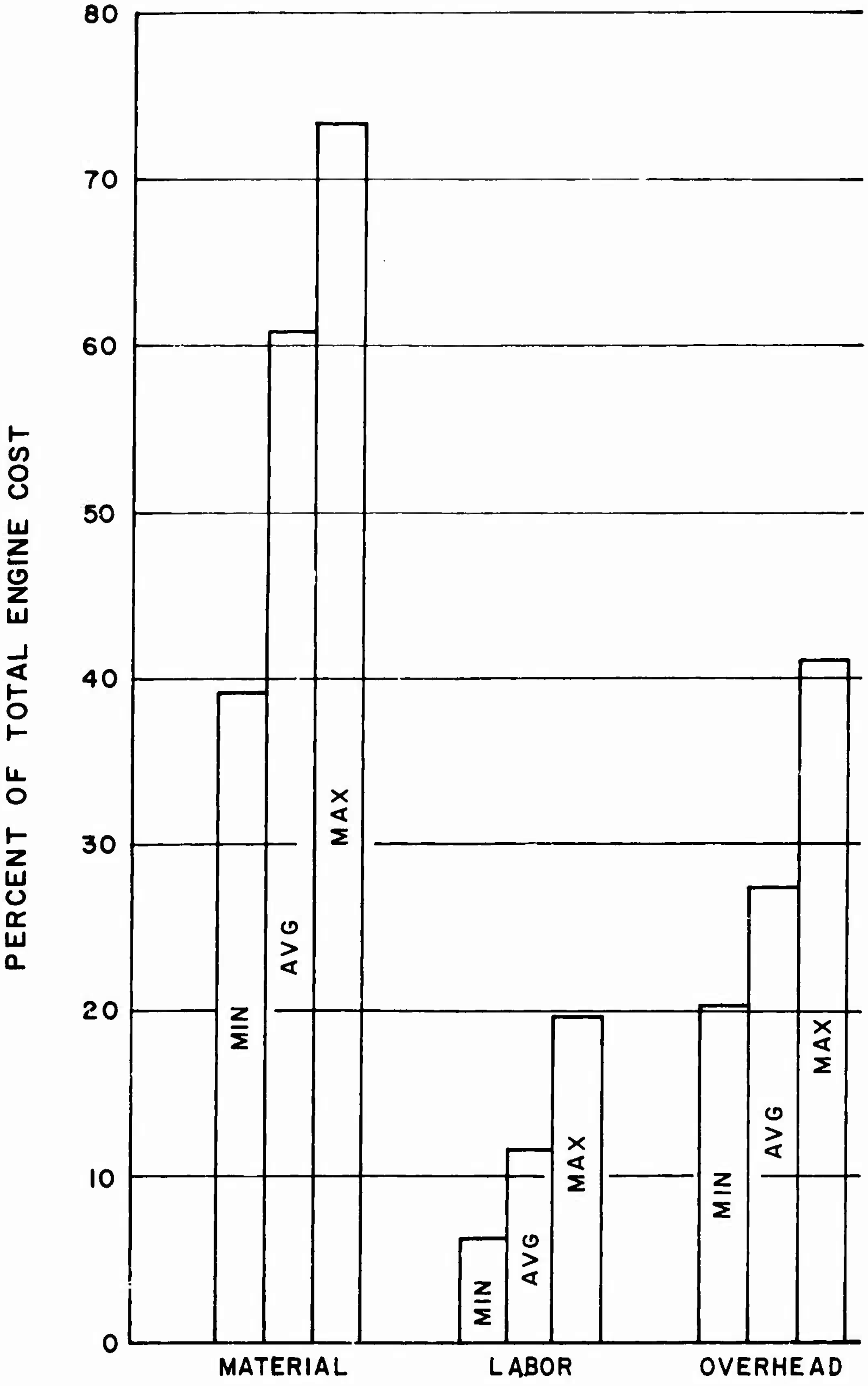

Figure 12. Material, Labor, and Overhead Costs in Percentage of Total Engine Cost at the 500th Unit.

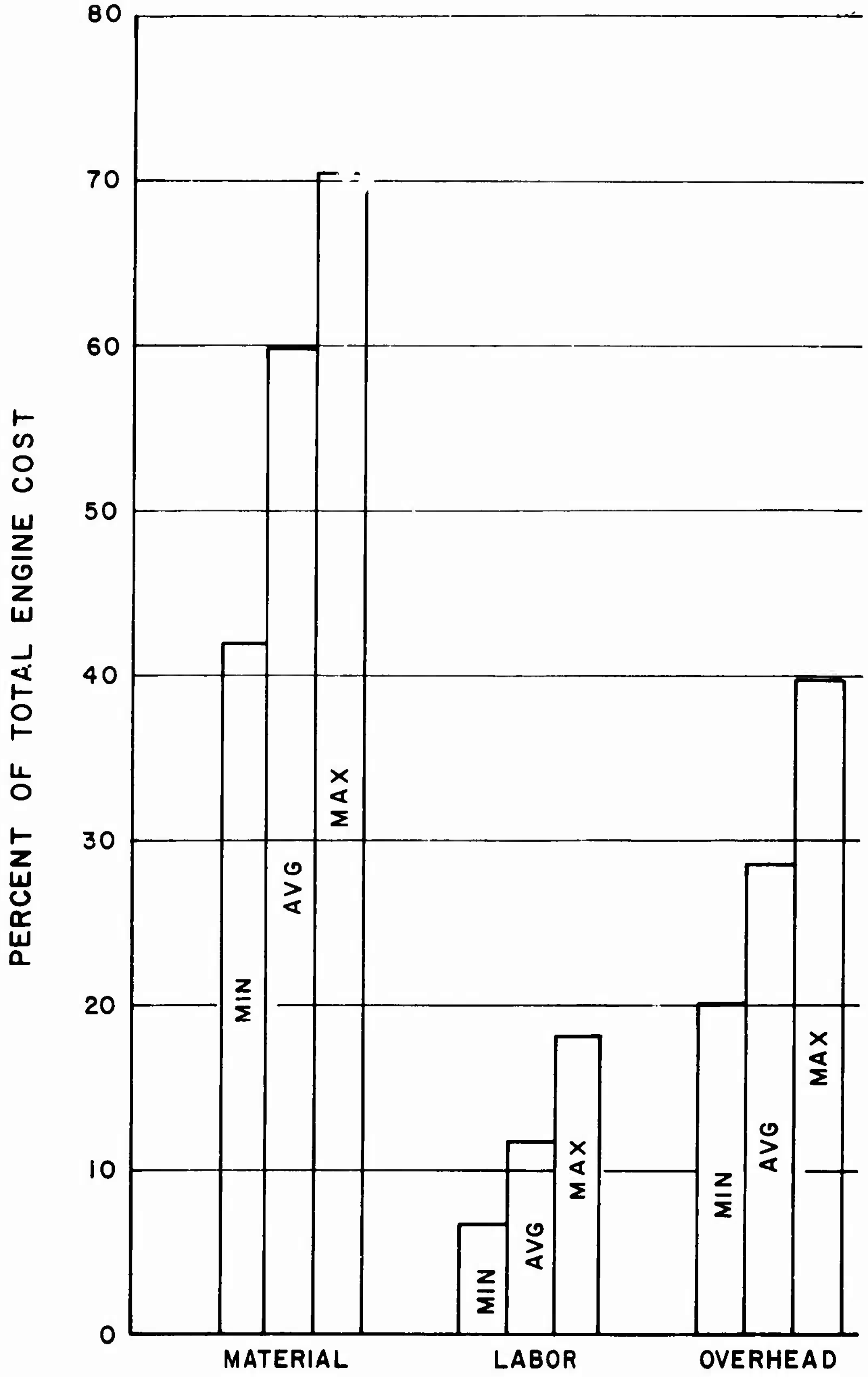

Figure 13. Material, Labor, and Overhead Costs in Percentage of Total Engine Cost at the 1000th Unit.

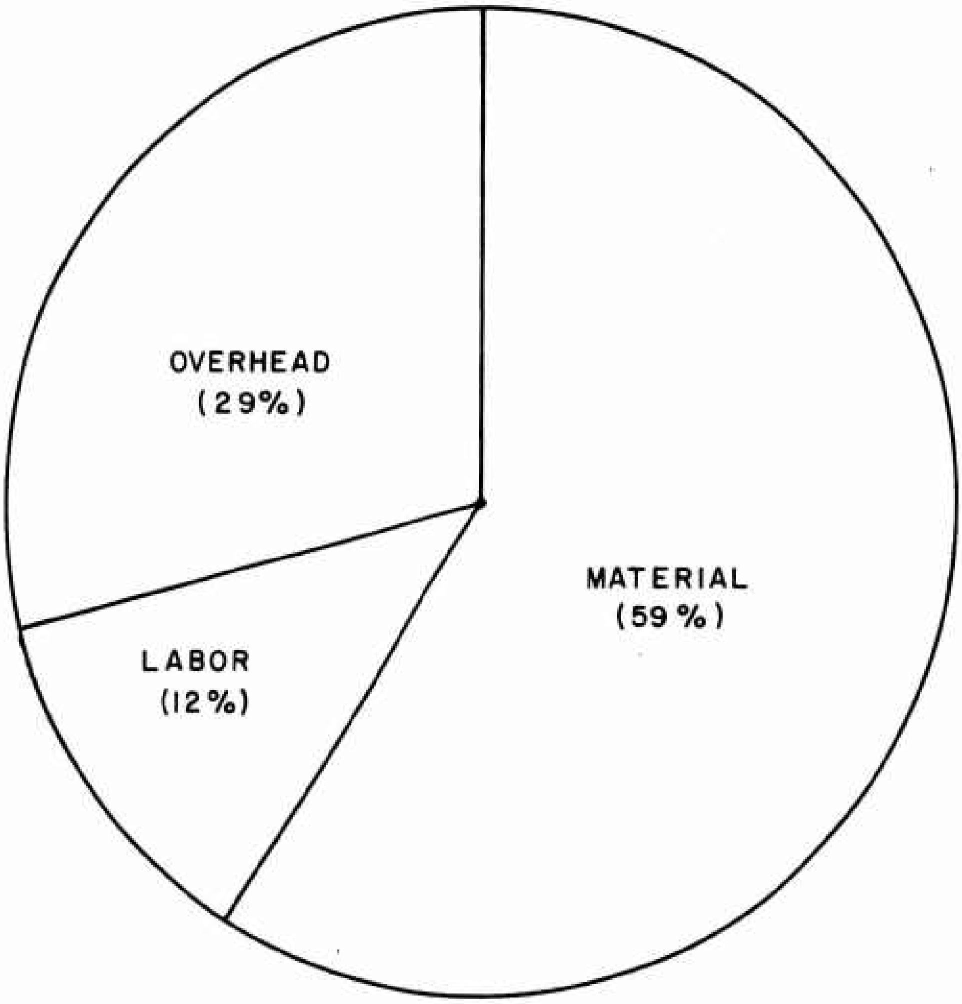

Figure 14. Average Breakdown of Engine Cost Into Material, Labor, and Overhead Costs.

represented by each of the three categories does not vary significantly from the 200th unit to the 1000th unit. This broad range between the maximum and minimum percentages of the engine cost for each of the three categories is probably largely attributable to differences in the accounting systems of the various engine manufacturers.

MATERIAL COST

The material cost represents, on the average, 59 percent of the total engine cost (Figure 4). Table III and Figures 11, 12, and 13 indicate that this figure can be as high as 75 percent. This figure can be misleading if we consider material cost to be only the cost of raw materials. However, in most cases the material cost includes all compressor and turbine blades and other purchased parts. In an extreme case, this material cost could include outside production of all components to the point that only final assembly would be required at the engine manufacturer's facility. The other extreme is the case where the majority of the parts are fabricated at the engine manufacturer's facility. In this case, the major portion of the materials cost would be made up of raw materials.

The plot of the variation of material cost with production level (Figure 15) makes it readily apparent that there are factors other than learning that significantly affect the so-called "learning curve". Figure 15 and the data in Table IV show that even though the average material cost exhibits a fairly normal, but shallow, learning curve, the curve for a single engine may be erratic and unconventional. This can be attributed to the action, and interaction, of several factors. Some of the factors that increase material cost are: inflationary increases in raw material cost, changes in material or fabrication technique to increase service life, and increases in vendors' labor and overhead costs, which appear as increased material cost to the engine manufacturer. On the other hand, factors which would

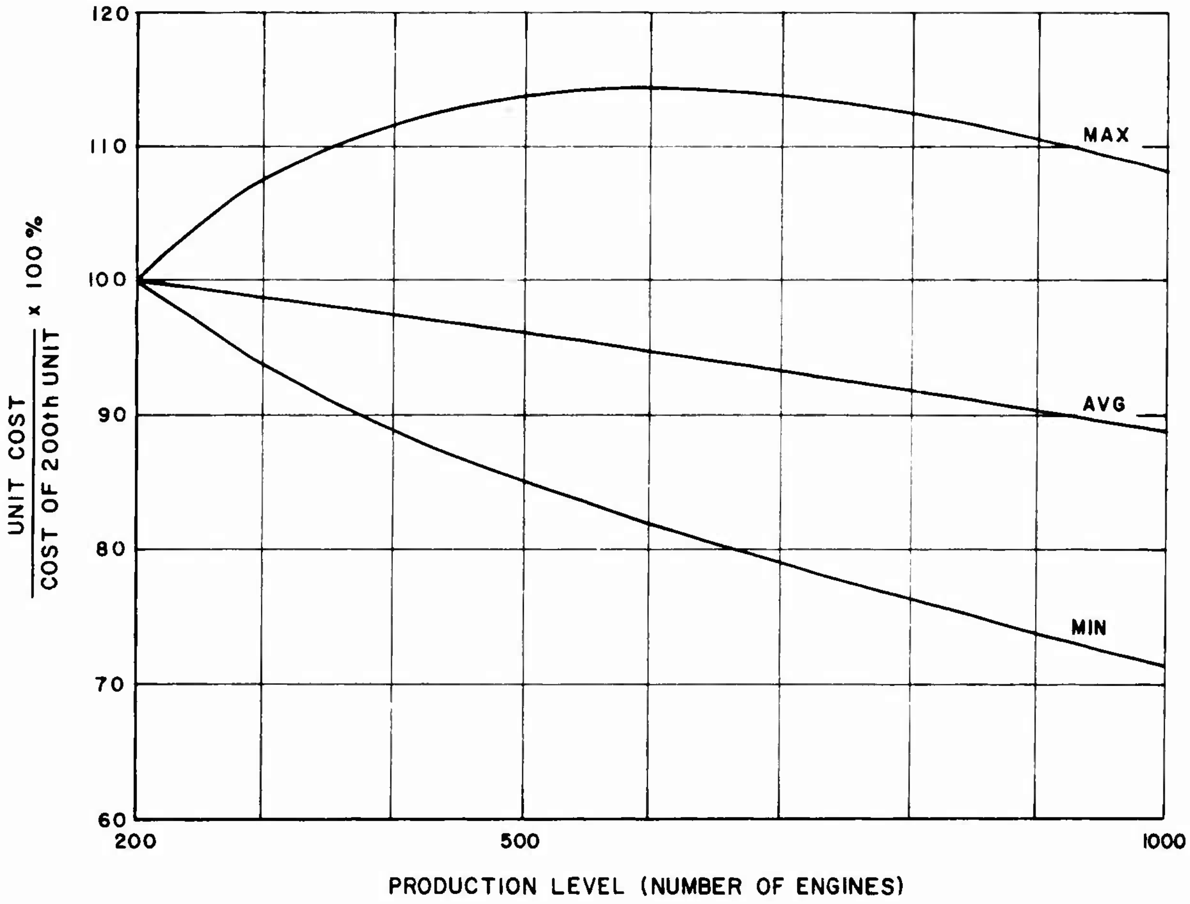

Figure 15. Material Learning Curve.

TABLE IV. MATERIAL, LABOR, AND OVERHEAD COSTS AT THE 500TH AND 1000TH UNITS AS A PERCENTAGE OF THEIR COST AT THE 200TH UNIT

	Engine				
	A (pct)	B (pct)	C (pct)	D (pct)	Avg (pct)
			500th Unit		
Material	113.9	96.2	88.8	85.1	96.0
Labor	87.4	76.6	102.5	58.2	81.2
Overhead	83.4	73.6	96.2	59.2	78.1
			1000th Unit		
Material	108.1	94.9	81.6	71.4	89.0
Labor	73.2	71.2	106.9	63.6	78.7
Overhead	72.2	62.7	111.4	61.5	77.0

tend to reduce material cost include: discounts based on larger order quantities, vendor learning curve on outside production, and changes to less expensive materials and fabrication techniques of noncritical parts. It should be noted that, although the average result of the action of these variables follows the general shape of a normal learning curve, the cost reduction due to increased production is relatively small. Figure 15 shows that the average cost of material for the 1000th unit is only 11 percent less than the cost of material for the 200th unit. For the total engine cost (Figure 5), the corresponding reduction is 19.4 percent.

LABOR COST

Labor cost ranges from as high as 21 percent to as low as 6 percent of total engine cost, with an average of 12 percent. This range in labor cost is explained in the same manner as the range in material cost. At the low end of the labor cost range, the only labor required is the final assembly of finished parts purchased from vendors; at the other extreme, the labor includes fabrication of these parts from raw material at the engine manufacturer's facility.

Labor cost as a function of production level follows more closely the normal learning curve (Figure 16). The upper limit of the curve shown in Figure 16 is seen from Table IV to represent only one engine, and its

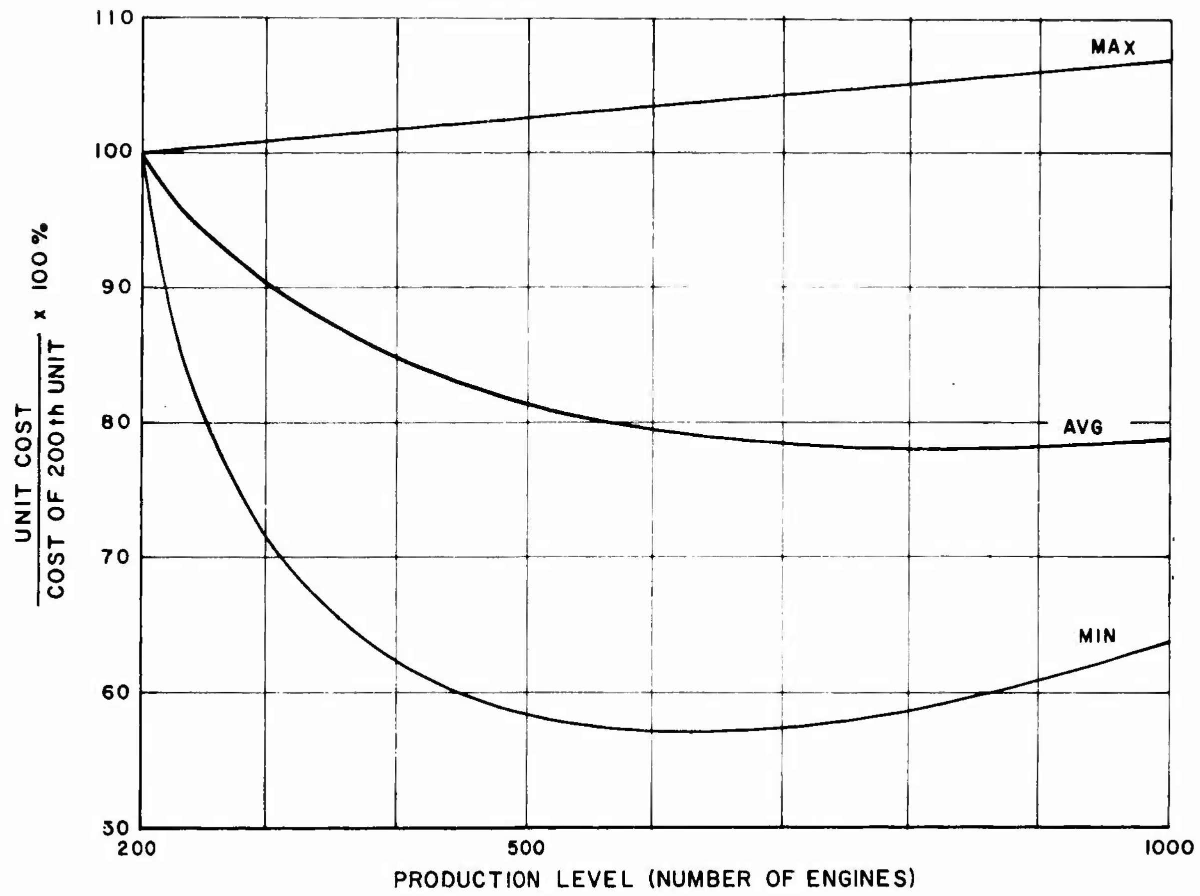

Figure 16. Labor Cost Learning Curve.

deviation from the normal curve is the result of rising labor rates. These rising rates more than offset the reduction in labor hours due to learning. Labor cost shows an average reduction of 21.3 percent from the 200th unit to the 1000th unit. This is almost 2 percent better than the average for the overall engine.

OVERHEAD COST

As might be expected from the wide range of material and labor costs, the range of overhead cost is also broad. This cost ranges from a high of 46 percent to a low of 19 percent of the total engine cost with an average value of 29 percent. Table III shows that for each engine, the overhead is a fairly constant multiple of the labor cost. This constant ranges from approximately 2 to approximately 3. Therefore, it is not surprising that the overhead cost learning curve (Figure 17) is very similar to the labor cost learning curve (Figure 16). On the average, the reduction in overhead cost from the 200th to the 1000th unit is 23 percent, which is 3.6 percent better than the average for the engine as a whole.

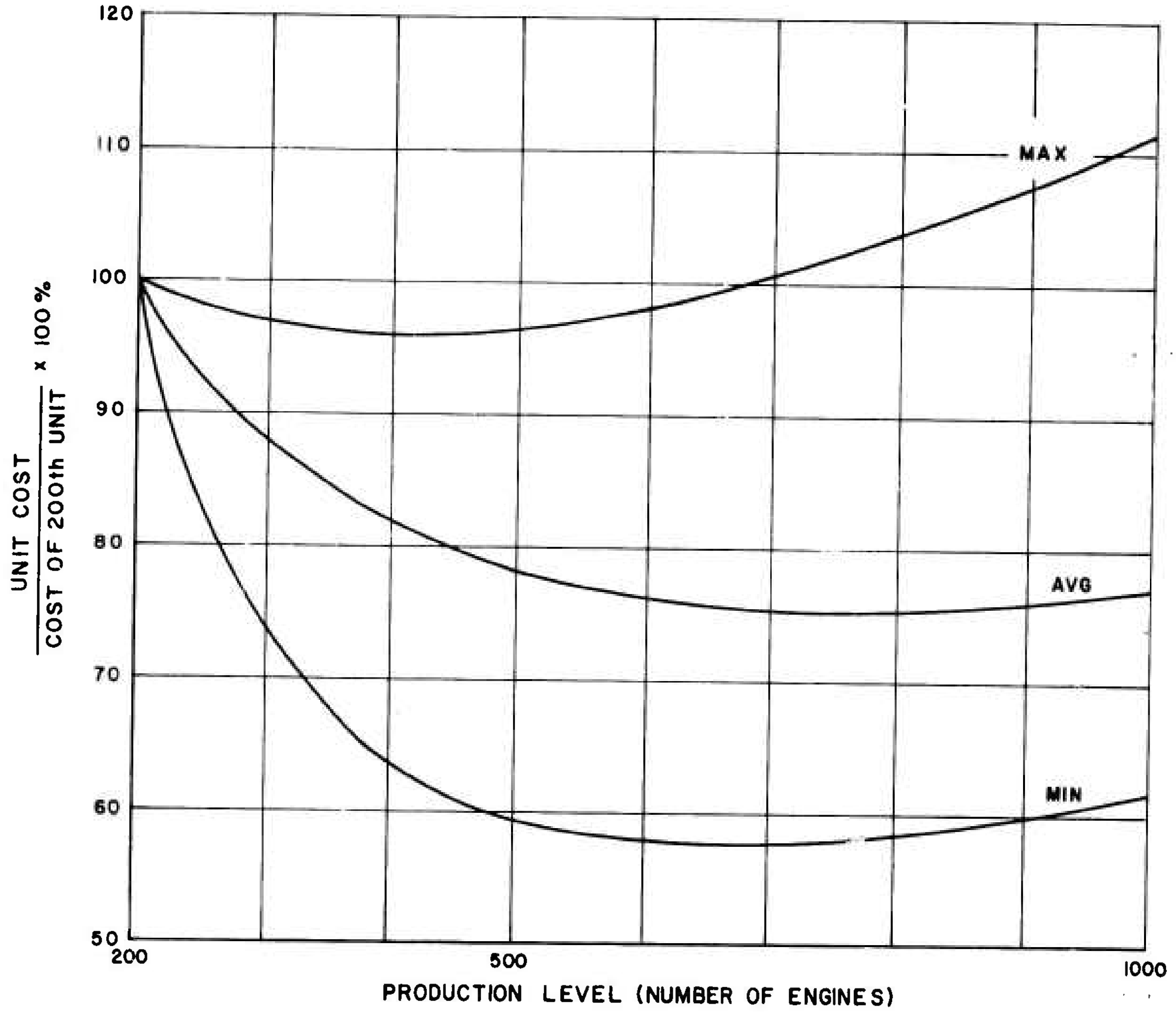

Figure 17. Overhead Cost Learning Curve.

CONCLUSIONS

Based on the data received, it is concluded that:

1. The component groups which make up the major portion of the total engine cost are the compressor, turbine, and accessories. These groups represent, on the average, 31.15 percent, 29.3 percent, and 27.6 percent, respectively, or a total of 88.05 percent of the total engine cost.

2. The most promising means of reducing compressor cost lies in the continuing advancement of compressor technology in the area of increased stage loading. Advances in this area would reduce the number of stages required for a given pressure ratio, and the compressor cost would decrease correspondingly.

3. The turbine represents one of the highest cost components in current production engines; and advanced engines with their higher turbine inlet temperatures, and associated cooling requirements, will force this percentage even higher. Advances in the area of increasing turbine stage work would have the same effect on turbine cost as increased stage loading has on compressor cost. The number of stages could be reduced with a corresponding reduction in turbine cost.

4. In the accessory area, the cost reduction due to increasing production (learning curve) is less than that for any other component. This lack of cost reduction is attributed in part to the fact that the majority of the components which make up this group are purchased as complete assemblies from outside vendors. This same lack of cost reduction in purchased parts is reflected again in the plot of material cost as a function of production level.

5. The combustor and the accessory drive represent a relatively minor portion of the total engine cost. In addition, their percentage cost reduction due to increased production (learning curve) is greater than that for the overall engine. These components do not appear to lend themselves to a further significant improvement in cost. This is not to imply that their cost should be ignored, but, rather, that specific, intensive cost-reduction programs in this area do not appear to be worthwhile.

6. The material cost makes up the majority of the total engine cost. It also follows a shallow learning curve. Material cost reduction is 8.4 percent less than average engine cost reduction from the 200th unit to the 1000th unit.

RECOMMENDATIONS

Based on the results of this study, it is recommended that:

1. Programs to advance compressor and turbine technology be continued, with the objective of reducing the required number of compressor and turbine stages.

2. Work be initiated in the area of turbine fabrication and cooling techniques, with the objective of minimizing the increase in turbine cost due to the cooling requirement.

3. Efforts be continued in the area of high-speed accessories, with the objective of reducing and eventually eliminating reduction gearing in the accessory drive system.

4. Additional cost studies be conducted based on a more detailed cost breakdown in the compressor, turbine, and accessories area. This detailed cost breakdown should reflect the cost structure of the individual parts, such as blades, vanes, nozzles, discs, impellers, diffusers, fuel controls and pumps, in an effort to pinpoint the high-cost items more accurately. From this study, specific cost-reduction programs could be initiated for the individual high-cost parts.

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13. ABSTRACT

It is anticipated that cost reduction will become an increasingly important factor in the future of the gas turbine engine. Therefore, it is considered to be necessary to establish a research program aimed at gas turbine engine cost reduction. The objectives of this program were to identify high-cost engine components and to examine the changes in their cost with increasing production. Cost data were solicited from all major gas turbine engine manufacturers relative to total engine cost and major component cost at various engine production levels. The data indicate that the compressor, turbine, and accessories are the highest cost components and that they represent, on the average, 88 percent of the total engine cost. Results also indicate that the accessories experience less cost reduction with increasing production than do any other engine components. In the compressor and turbine area, the most promising means of cost reduction appears to be simply reduction of the number of stages through advances in compressor and turbine technology. The results of this program further indicate the need for a more detailed study in the compressor, turbine, and accessory areas.

14. KEY WORDS	LINK A		LINK B		LINK C	
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