The Influence of Engine Characteristics on Patrol Aircraft Life Cycle Cost Optimization

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INTRODUCTION

This paper is based on results achieved by the Lockheed-California Company during the Task 1 portion of the Advanced Technology Engine Study (ATES). The work was performed in support of Detroit Diesel Allison (DDA), which was under contract to the U.S. Navy. The subject of the study was the propulsion system for a conceptual maritime patrol aircraft (MPA). The sequence of subtasks included the following:

- Selection of a baseline aircraft from previous studies
- Definition of missions and duty cycles
- Sizing of a point design aircraft, using scalable DDA study engines, based on minimum takeoff gross weight (TOGW)
- Calculation of TOGW sensitivity to engine parameters
- Sizing of point design aircraft, using same scalable engine, based on minimum life cycle cost (LCC)
- Calculation of LCC sensitivity to engine parameters

The data for the scalable study engine model called the PD430-1 were supplied by DDA.

Topics of emphasis in this paper are:

- Methodology for optimization of patrol aircraft designs
- Correlation of LCC to TOGW
- Sensitivity of aircraft costs to changes in engine characteristics

MPA CONCEPT DESCRIPTION

The MPA is conceived to be a land-based, airborne antisubmarine warfare (ASW) system, which would initially supplement and eventually replace the current U.S. Navy/Lockheed P-3 patrol aircraft. Initial operational capability would occur about 1995. As envisioned by U.S. Navy planners, the MPA would have the basic ASW role plus antisurface warfare (ASUW), ocean surveillance, and mining capabilities.

Relative to the P-3, the MPA would have increased endurance/range capability, higher speed, a larger payload, expanded capability for secondary missions, and improved habitability. Powerful radars and extensive avionics would provide far greater air and surface surveillance performance. Self-protection systems would include long-range passive sensors, electronic and infrared countermeasures, and perhaps short- or medium-range air-to-air missiles, although such missiles are not included in the design payload.

Baseline Aircraft

The baseline aircraft was an MPA configuration which was derived from previous Lockheed work. The aircraft, shown in Fig. 1, was a low-wing, four-engine turboprop configuration using four 10-bladed propfans based on Hamilton-Standard data. The engines were scalable turboshaft engines, representing 1985-1988 technology, and were optimized in size for this application. The airframe made significant use of advanced composite materials. The size of the aircraft was determined by the design mission flight profile, illustrated in Fig. 2, which included a cruise out and back to an ASW.
station, with a 4-hour loiter on station at altitude. The design payload included ASW and ASUW expendable stores, which were assumed to be retained on board throughout the flight profile. The design included significant weight and performance penalties associated with fuel-tank explosion suppression techniques for enhanced survivability, and with acoustic treatment for reduced cabin noise levels. The TOGW was 165,021 pounds (74,853 kg).

**MPA UTILIZATION**

To establish an engine duty cycle for the MPA, it was necessary to postulate the utilization of the aircraft. All of the weight and performance data in this section are related to the baseline aircraft.

**Mission Definition**

The design mission flight profile is consistent with the wartime performance requirements for future patrol aircraft. Utilization of the MPA in peacetime, however, would probably be similar to the pattern of utilization of the P-3C. Accordingly, pilots’ reports for P-3C flights in 1979 were reviewed, three representative peacetime flight profiles were formulated, and the relative frequency of each of the three flight types was estimated. The missions were called Pilot Training, Representative ASW, and Surface Surveillance. Results are given in Table 1.

<table>
<thead>
<tr>
<th>MISSION</th>
<th>PERCENTAGE BY SORTIE</th>
<th>PERCENTAGE BY HOURS</th>
</tr>
</thead>
<tbody>
<tr>
<td>REPRESENTATIVE ASW</td>
<td>33</td>
<td>49</td>
</tr>
<tr>
<td>PILOT TRAINING</td>
<td>52</td>
<td>32</td>
</tr>
<tr>
<td>SURFACE SURVEILLANCE</td>
<td>15</td>
<td>19</td>
</tr>
</tbody>
</table>

**Table 1** MPA Utilization

The general trend toward increasing use of ground-based simulators suggests that aircraft utilization in the 1990s might include a smaller percentage of training flights and a corresponding increase in the relative frequency of ASW flights. No method was identified for quantification of this trend, however, and no modifications were made to the utilization projections for the MPA. Each operational aircraft was assumed to log 1020 flight hours per year.

The power time history for the design mission is shown in Fig. 3. The power time history was defined in terms of three ratings: maximum (5 minutes), intermediate (30 minutes), and maximum continuous. The maximum rated power was approximately 122 percent of intermediate power. Engine cycles were not counted for this mission because the mission was not included in the peacetime utilization.

For each of the three representative peacetime missions, flight profiles and power time histories were formulated. The number of engine cycles was calculated for each mission using the following definitions of cycle types:

- **Type I** — Start to maximum to shutdown
- **Type IIIA** — Idle to maximum to idle
- **Type IIIB** — Idle to intermediate to idle
- **Type IV** — Idle to part power to idle

**Cycle Data Summary**

Using the cycle data for the three typical missions and the utilization assumptions as stated above, composite utilization data were calculated. These data are presented in Table 2. They can be useful in the estimation of engine durability requirements and maintenance costs.

<table>
<thead>
<tr>
<th>MISSION TIME</th>
<th>1,020 HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO. OF CYCLES PER YEAR</td>
<td>TYPE I 158.4 PER 1,000 HR</td>
</tr>
<tr>
<td></td>
<td>IIIA 408.16 PER 1,000 HR</td>
</tr>
<tr>
<td></td>
<td>IIIB 294.02 PER 1,000 HR</td>
</tr>
<tr>
<td></td>
<td>IV 0 PER 1,000 HR</td>
</tr>
</tbody>
</table>

| HOT TIME PER YEAR | AT MAX 17.57 HR (1.72%) |
|                  | AT INTERMEDIATE 100.58 HR (10.45%) |

**Table 2** Cycle Data: All Missions

All of the flight profiles and power time histories are relatively smooth, and the number of cycles per flight hour is much lower than those data which have been estimated for military aircraft such as fighters. In general, this smoothness was presumed to be valid because the MPA would be equipped with a computerized flight management system and would be flown in much the same manner as a commercial airliner. To add an additional degree of realism, however, it was determined that high-frequency, low-amplitude throttle dynamics should be superimposed on the mean throttle setting in the loiter segments of the flight profiles.

**PROPELLION SYSTEM DESCRIPTION**

The new propulsion system for the resized MPA consisted of advanced technology engines and gearboxes compatible with a 1995 IOC; the propellers were of the same design as those on the baseline aircraft.

**Engine**

The PD430-1 is an axial-flow turboprop engine with a single-spool core, free power turbine, and offset reduction gear assembly.
Advanced technologies are incorporated to improve engine performance, reliability, and durability compared to current state-of-the-art propulsion systems. Correspondingly, the technologies are intended to produce reductions in engine size, maintenance costs, and overall life cycle costs. The basic design philosophy includes:

- Improved component efficiencies
- Advanced materials and processes
- Simplified design and minimized number of parts
- High-cycle pressure ratio and temperature

The high-performance compressor is a multistage, high-pressure-ratio design with low-aspect-ratio blading and low-inlet-hub/tip-diameter ratio. The inlet specific annular airflow is increased beyond current levels. The inlet guide vanes and first five stages of stators are variable to provide good performance and surge margin throughout the operating range. All vane stages are inherently designed for rugged construction. The annular diffuser/compressor module includes a vortex-controlled diffuser which represents a significant advancement in state-of-the-art design for low losses and reduced length.

The high-pressure turbine is an air-cooled, two-stage design that has unshrouded blades. Cooling air temperature and circuitry is used to provide rotor blade active tip clearance control to maintain high efficiencies over a wide range of operating conditions. Advanced airfoil cooling technologies are included to minimize cooling air requirements.

The power turbine is a three-stage configuration with shrouded blades. The gas generator spool is supported by three rigidly mounted bearings. The power turbine shaft is carried by three bearings, one of which has squeeze film dampers. The shaft is subcritical due to the material used.

The engine also includes an accessory gearbox attached to the bottom of the compressor air inlet housing, a fully contained lubrication system, and a full-authority digital electronic control. The oil system supplies the reduction gearbox and the propfan. The control system is integral with the propfan. Primary engine mounts are on the gearbox with a hang mount at the rear of the engine.

The engine has a design/match point that corresponds to the initiation of outbound cruise at maximum continuous power for the MPA design mission. The engine is set up on the basis of turbine rotor inlet temperature (RTT), wherein a selected RTT is used to define power rating. The intermediate rating provides sufficient power margin for takeoff and climb under standard day conditions. Although the intermediate temperature may be sufficient on a tropical day (90°F, 32.2°C), an extra 50°F (27.8°C) RTIT is provided for additional power margin.

Gearbox

The reduction gearbox was an all-new design provided by DDA. Compared to the T56 series of gearboxes, such as that used in the P-3, it was a simplified design. It was configured to provide reliability, maintainability, and cost advantages. The gearbox was offset downward to accommodate over-the-wing engine mounting. The gear ratio provided a propfan speed of 1570 rpm. A drive pad for remotely mounted aircraft accessories was provided on the back of the gearbox.

Propeller

The propeller design used for the baseline MPA was retained for this study. This propeller is actually a Hamilton-Standard propfan capable of efficient operation at airspeeds up to Mach 0.8. If the propeller had been reoptimized for this MPA, with its cruise speed of only Mach 0.7 rather than Mach 0.8, the design would probably have featured a smaller number of blades with less extreme twist and sweep on each blade, but the cruise efficiency would not have been significantly different.

MPA SIZING: TOGW

This section describes the results of the MPA sizing task with minimum takeoff gross weight (TOGW) as the criterion. The sizing procedure is to vary the scale of the propulsion system and aircraft to obtain designs whose capabilities match the design mission flight profile and then to select a minimum TOGW point design from among those designs.

In accordance with Lockheed's most recent recommendations concerning operational requirements for an MPA, the design payload was taken to be 2000 pounds (907.2 kg) greater than that which had been used for the baseline aircraft.

Parametric Sizing

The sizing parameters were aircraft thrust to weight ratio (T/W) and wing loading (W/S). The point to be selected was that which represented the minimum TOGW but met all constraints.

Fig. 4 is a carpet plot showing the results of this analysis. All points on the surface represent aircraft which would meet the mission requirements in terms of payload, time on station, and radius of action. Constraint No. 1, plotted on the chart, is a requirement that the available fuel volume in the wing exceed the necessary fuel volume by 5 percent. This constraint imposes an upper limit on wing loading. Only those points below approximately 107 lb/ft² (512.3 Pa) met the requirement.

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Fig. 4 Takeoff gross weight sizing

The second operative constraint is that thrust available at maximum continuous power must exceed the thrust required to establish an initial cruise at Mach 0.7. Fig. 4 illustrates that constraint No. 2 tends to establish a lower bound on T/W.

A third constraint, an 8000-foot critical field length (CFL), was not plotted in Fig. 4 because all points on the chart easily complied.

Point Design Selection

The minimum TOGW point design occurs at the intersection of the two constraints. The proximity of the point design location to the bottom of the matrix is simply an indication that the point design TOGW was surprisingly low. Even with a correction for the difference in payload weights, the new design is substantially lower in TOGW than the baseline aircraft. One of the contributing factors is the difference in engine margins policy; the baseline aircraft had used "minimum" engines while the new design used "average" engines.

The thrust-to-weight ratio of the selected point design was 0.2104 lb/lb (2.063 N/Kg) and the wing loading was 106.9 lb/ft² (5118 Pa).

A weight breakdown of the point design, in terms of functional groups, is presented as Table 3. It can be seen that the propulsion group represents only 7 percent of TOGW; in turn, the engine and gearbox together constitute only about one third of the propulsion group weight.

It is significant that cruise thrust requirements, rather than takeoff thrust requirements, determined the size of the engine. This situation suggests that a better aircraft and engine match could be
Table 3  Point Design Weight Breakdown

<table>
<thead>
<tr>
<th>Category</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty Weight</td>
<td>51.3</td>
</tr>
<tr>
<td>Propulsion Group</td>
<td>7.0</td>
</tr>
<tr>
<td>Structure Group</td>
<td>23.9</td>
</tr>
<tr>
<td>Systems Group</td>
<td>20.4</td>
</tr>
<tr>
<td>Operating Items</td>
<td>3.0</td>
</tr>
<tr>
<td>Expendable Stores</td>
<td>9.9</td>
</tr>
<tr>
<td>Growth Allowance</td>
<td>0.8</td>
</tr>
<tr>
<td>Fuel</td>
<td>35.0</td>
</tr>
<tr>
<td>Takeoff Gross Weight</td>
<td>100.0</td>
</tr>
</tbody>
</table>

NOTE: Propulsion Group includes engines, exhaust systems, engine controls, propellers, gearboxes, engine and gearbox lubricating systems, and the entire fuel system. It does not include nacelle structure.

Achieved if the cruise speed requirement could be reduced. It could also be inferred that the maximum rating on the engine is unnecessary. Takeoff performance superior to the requirement would be highly desirable under many circumstances, however, so no such rerating was recommended.

Sensitivities

The aircraft design is not sensitive to small (i.e., ±5 percent) changes in engine length or diameter since neither of these parameters determined the size or shape of the nacelle. As can be seen in Fig. 5, the sensitivity of TOGW to engine weight is very small also.

The sensitivity of TOGW to changes in specific fuel consumption (SFC), as represented by fuel flow at the required thrust, is more pronounced. The data are presented in Fig. 6. The difference in the scale of the ordinates on Figs. 5 and 6 should be carefully noted.

Note that all points on the sensitivity curves do not represent optimized aircraft, but they are close enough to compliance with the constraints for study purposes.

MPA SIZING, LIFE CYCLE COSTS

The sizing of the MPA using the minimum TOGW as the criterion was performed to provide a preliminary estimate of the required engine characteristics. Ultimately, however, the sizing and sensitivity studies had to be done in terms of life cycle cost (LCC) so that tradeoffs could be performed by DDA against other factors in terms of dollar costs.

The same 16 MPA designs (i.e., combinations of T/W and W/S) used in the TOGW analysis, as shown in Fig. 4, were used to construct the LCC sizing matrix presented in Fig. 7. The shape of the matrix is nearly identical to that shown in Fig. 4, which means that TOGW and LCC are highly correlated. Moreover, the shape of the constraint lines is also preserved, so that the point design would once again be selected at the intersection of the constraints. Thus the point design selected on the basis of minimum LCC is exactly the same design which had been selected on the basis of minimum TOGW, and all previously stated sizing and sensitivity data are still applicable.

The results described above were based on an assumed fuel cost of $1.80 per U.S. gallon ($0.476 per liter). If fuel costs were $3.60 per U.S. gallon ($0.951 per liter), the sizing matrix would appear as in Fig. 8. The absolute values of LCC have changed, but the shape of the matrix has varied only slightly, and the characteristics of the minimum LCC point design would remain exactly the same. The message is clear: fuel cost is not a driving factor in optimization of an MPA. If fuel price dropped from $1.80 per U.S. gallon ($0.476 per liter) to $0.90 per U.S. gallon ($0.238 per liter), LCC would drop only 5.5 percent; if fuel cost increased to $3.60 per gallon ($0.952 per liter), LCC would increase by 11 percent.

FUEL PRICE = $1.80 PER GALLON ($0.476 PER LITER)

Fig.7 Life cycle cost sizing

FUEL PRICE = $3.60 PER GALLON ($0.951 PER LITER)

Fig.8 Life cycle cost sizing
One might legitimately wonder whether any level of fuel price could alter the optimization of the MPA. As a by-product of the LCC analysis, the optimization for a minimum-fuel-burn design was obtained. Such an optimization would represent an upper bound on the importance of fuel in a minimum LCC optimization. For this case, the point design would no longer be located at the intersection of the two constraints, but rather it would have a T/W of about 0.23 lb/lb (2.255 N/kg) and a W/S of about 100 lb/ft² (4788 Pa). The TOGW would increase about 0.8 percent. The fuel burned to thousands of dollars per gallon before the minimum-fuel-burn design would have a lower LCC than the selected point design.

Point Design Costs

The cost models employed for this study are those developed by Lockheed for the cost assessments of new, advanced Navy maritime patrol aircraft. The cost models are designed to be sensitive to engine configuration, performance, and cost variations in order to assess weapons system life cycle cost trends as well as to be able to identify any resultant cost impacts. They are structured to accept values from DDA propulsion subsystem life cycle cost calculations. Close coordination between Lockheed and DDA was maintained in the form of personal oral exchanges and written coordination memos to ensure consistent and duplicable cost estimation methodologies and printed output formats.

For these analyses, Lockheed postulated new maritime patrol aircraft programs which called for the design, development, and procurement of all-new airframes, propulsion, and avionics. For research, development, test, and evaluation (RDT&E), six prototype aircraft would be built for ground and flight test purposes; in production, 200 follow-on aircraft would be produced and delivered to the Navy's operational inventory. During the 20-year operating and support (O&S) time period, an average of 167 aircraft are expected to fly at the presumed annual peacetime utilization rate of 1020 flight hours per aircraft.

For the elements included in integrated logistics support (ILS) are assessed in the RDT&E and production phases at cost levels consistent with realized Navy experience for maritime patrol aircraft.

In the RDT&E and production phases, the nonrecurring costs are for those one-time expenditures which are more or less fixed, regardless of the number of aircraft to be produced. The recurring costs, however, are for those repeated fabrication, assembly, and checkout activities relating to aircraft manufacture as a function of the quantity produced. Cost breakdown summaries are provided in Tables 4 and 5 for the RDT&E and production phases, respectively, with the recurring and nonrecurring portions combined.

Table 4 RDT&E Cost Breakdown

<table>
<thead>
<tr>
<th>PRIME MISSION SYSTEM</th>
<th>72.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIRFRAME</td>
<td>26.6</td>
</tr>
<tr>
<td>PROPULSION</td>
<td>9.1</td>
</tr>
<tr>
<td>AVIONICS</td>
<td>28.7</td>
</tr>
<tr>
<td>CHANGE ALLOWANCE</td>
<td>6.7</td>
</tr>
<tr>
<td>SYSTEMS ENGINEERING</td>
<td>1.2</td>
</tr>
<tr>
<td>DATA</td>
<td>0.1</td>
</tr>
<tr>
<td>TOTAL RDT&amp;E</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Table 5 Production Cost Breakdown

<table>
<thead>
<tr>
<th>PRIME MISSION SYSTEM</th>
<th>72.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIR VEHICLE</td>
<td>71.1</td>
</tr>
<tr>
<td>AIRFRAME</td>
<td>26.6</td>
</tr>
<tr>
<td>PROPULSION</td>
<td>9.1</td>
</tr>
<tr>
<td>AVIONICS</td>
<td>28.7</td>
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<tr>
<td>CHANGE ALLOWANCE</td>
<td>6.7</td>
</tr>
<tr>
<td>SYSTEMS ENGINEERING</td>
<td>1.2</td>
</tr>
<tr>
<td>DATA</td>
<td>0.1</td>
</tr>
<tr>
<td>TOTAL PRODUCTION</td>
<td>100.0</td>
</tr>
</tbody>
</table>

It is important to note the difference between the definitions of "propulsion" in the weight and in the cost breakdown structures before attempting any comparisons. In the weight breakdown, the propulsion group included far more than the engine and gearbox. As stated earlier, the propulsion group was 7 percent of TOGW but the engine and gearbox alone were only slightly more than 2 percent of TOGW.

The propulsion costs, which include the engine, gearbox, and propeller, amounted to 9.1 percent of production cost. If the propeller were excluded, then the engine/gearbox combination would account for about 7.7 percent of production costs. These are only the direct costs, of course, and it is difficult to determine what portion of cost elements such as project management and change allowance could be attributed to propulsion. Fortunately, it is not necessary to resolve a propulsion cost fraction to assess the approximate impact of engine costs on aircraft life cycle costs.

Table 6 provides the estimated operating and support (O&S) cost breakdown on a per-aircraft-per-year basis. The annual aircraft O&S costs were translated to 20-year aircraft fleet costs by multiplying the number of operational aircraft (167) and then by 20 years.

Table 6 Operating and Support Cost Breakdown

It can be seen that those O&S expenses directly attributable to the engine — i.e., engine rework — are rather small. Again, it is difficult to assess what fraction of the total maintenance costs could be considered as "propulsion related". The fuel cost is approximately one fourth of total O&S expense.

Life cycle costs were determined by summing the RDT&E, production, and 20-year O&S costs. These costs were all calculated in terms of constant value (rather than inflated) dollars. A life cycle cost breakdown is presented in Table 7. Considering the data in Tables 6 and 7, it can be seen that fuel and oil expenses constitute 11.1 percent of life cycle costs.
Sensitivity Studies

The final task was the determination of the patrol aircraft life cycle cost sensitivity to change in engine characteristics. The sensitivity of aircraft LCC to changes in engine weight or engine fuel flow requirements was calculated. Engine diameter and length were not considered as variables because changes of less than 5 percent in these quantities would not alter the contours of the nacelle, so that there would be no change in aircraft drag. Engine thrust was not used as an independent variable because the sizing process includes the scaling of available thrust to match required thrust.

The results of the sensitivity study are presented in Fig. 9. Life cycle costs are shown for both the baseline and doubled fuel prices.

Table 7 Life Cycle Cost Breakdown

<table>
<thead>
<tr>
<th>Parameter Variation</th>
<th>Fuel Flow</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-10%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20%</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Fig. 9 Life cycle cost sensitivity study results

Throughout the sensitivity study, T/W and W/S were held constant. Thus, the data points do not represent reoptimized aircraft designs, but the values of the fuel-volume ratio, thrust margin, and takeoff distance parameters were monitored.

The data show that the variations in fuel flow are far more significant than the variations in engine weight. In fact, the effects of the latter are barely measurable. A variation of ±5 percent in SFC would change TOGW by about ±3.4 percent and LCC by about ±1.5 percent, assuming a fuel price of $1.80/gal ($0.476/liter). Only in the case of a ±5 percent variation in SFC did the design deviate from the constraints to the extent that reoptimization would have resulted in a measurably different aircraft.

Two additional sensitivities were investigated; these dealt with sensitivity of LCC to engine maintenance and recurring costs. These investigations did not require retooling of the aircraft design. Results are presented in Fig. 10. It should be noted that the scales on

Fig. 10 are quite different from those used on Fig. 9. It may be observed from Fig. 10 that a 20 percent change in either engine recurring cost (i.e., sales price) or engine maintenance cost would effect a change in system life cycle cost of approximately 1 percent. Whether or not such a change is regarded as significant depends upon the perspective of the observer; 1 percent of MPA fleet life cycle cost would probably be about $200 million dollars.

The data shown in Figs. 9 and 10 can be used to analyze some cost/performance tradeoffs in engine design. For example, if a certain engine design change would reduce fuel flow requirements by 1 percent but would cause a 10 percent increase in the price of the engine, then it would not be cost-effective because the former would reduce MPA fleet LCC by 0.3 percent, but the latter would increase LCC by 0.6 percent. Only a 5-percent increase in engine price could be tolerated for a 1-percent fuel flow reduction.

CONCLUSIONS

Several key observations on the study results are presented below:

- Performance requirements and sizing constraints form tight boundaries on the selection of the characteristics of the point design. In particular, the same point design is selected on the basis of minimum LCC as would be selected on the basis of minimum TOGW.
- Fuel price is not a significant factor in the optimization of an MPA. Only if fuel prices increased by several orders of magnitude would the characteristics of a minimum-LCC point design be significantly different from those of a minimum-TOGW point design.
- Engine size is determined by cruise rather than takeoff thrust requirements.
- MPA TOGW and LCC exhibit a strong sensitivity to variations in engine SFC. Only a slight sensitivity to engine weight was found. There is no sensitivity to a ±5-percent variation in engine diameter or length because the contours of the nacelle would not be altered. Only in the case of a ±5-percent variation in SFC would the change in engine characteristics require a reoptimization of the aircraft design.
- A 20-percent change in either engine recurring cost (i.e., sales price) or engine maintenance cost would effect about a 1-percent change in MPA fleet life cycle cost.

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