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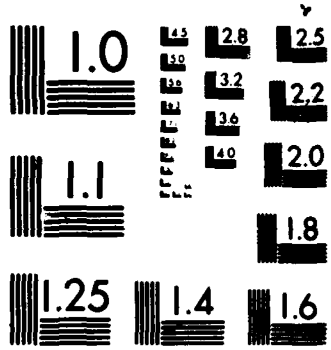

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POLICY OPTIONS FOR THE AIRCRAFT TURBINE ENGINE COMPONENT IMPROVEMENT PROGRAM

J. R. Nelson
B. R. Harmon
K. W. Tyson

May 1987

Prepared for
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The aircraft turbine engine Component Improvement Program (CIP) is an important element in the acquisition and maturation of engines for military aircraft and helicopter applications. This report presents the results of an investigation into the role of CIP, its value to the military services, and the feasibility and practicality of certain policy options including: 1) transitioning CIP to the private sector, 2) competing CIP in whole or in part, and 3) comparing CIP to airframe and avionics engineering change processes. Recommendations for future actions are included.

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J. R. Nelson
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K. W. Tyson

May 1987

INSTITUTE FOR DEFENSE ANALYSES

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PREFACE

This Report was prepared by the Institute for Defense Analyses (IDA) for the Office of the Under Secretary of Defense (Acquisition) under contract MDA 903-84-C-0031, Task Order T-A7-484, issued December 1986, and amendment.

This study addresses an issue raised by the Congress under Public Law 99-1005, Joint Appropriations Act for Fiscal Year 1987.

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I. INTRODUCTION AND SUMMARY

A. INTRODUCTION

The aircraft turbine engine has been a technical and financial success for the United States. The United States became the world leader in developing and producing these engines for military and commercial markets during World War II and has maintained that leadership through a sustained and substantial effort over the past four decades.

Changes have occurred in the development and production of engines during this period that have improved their quality substantially. One element of the engine acquisition process in the military services that has contributed to this improvement is the Component Improvement Program (CIP). CIP continues the maturation of an engine after it begins operational use. Military engines are not unique in this regard. Commercial engines also require continuing engineering support following development. The objective of the military services is to attain the balance of full scale development (FSD) and CIP activities that fields superior equipment at the earliest practical date.

There have been many studies of military aircraft turbine engine development and CIP during the past several decades. (See the Bibliography at the end of the report.) Changes in CIP have occurred, but questions continue to surface. Another study of CIP has been ordered by the Congress. Under Public Law 99-1005, the Under Secretary of Defense (Acquisition) was directed "to examine the feasibility of gradually transitioning the financial support for these programs to the private sector." Because of the continuing Congressional interest in aircraft turbine engine development and CIP, and because of recent initiatives in DoD, the Office of the Under Secretary of Defense (Acquisition) thought it appropriate to broaden this study to investigate not only the issue of privatization specified in the law, but also the role of CIP, the costs and benefits of the program, and the policy options of competing CIP funding and possibly achieving improvements in other ways.

In addressing the issue of transitioning CIP to the private sector, consideration is given to accomplishing transition by mission area, by time phase within a program, and by objectives and functions of CIP. Competition for CIP funding is examined in a similar manner, including consideration of the resources required by companies to compete. In investigating other possible ways of achieving improvements, the approaches used for airframe and avionics equipment are examined. For all the issues, government and industry objectives and incentives are central concerns.

B. FINDINGS

1. The Role of CIP

CIP is an integrated sustaining engineering effort that extends the maturation period for aircraft turbine engines following FSD.

CIP objectives are:

- To correct safety of flight problems, service revealed deficiencies in operational use, and failures induced early in accelerated mission testing and lead-the-force operations
- To improve durability, reliability, maintainability, producibility, and repairability
- To reduce parts cost, engine cost, and life cycle cost (including fuel cost)
- To provide logistics support planning, integration of total effort to obtain improvements, and opportunity for new technologies insertion
- To retain performance over the engine lifetime in the inventory.

CIP functions include:

- Engineering analysis and design, manufacture of parts for testing, testing of parts and engines, quality control of parts and engines, and management integration of CIP

The resources required to accomplish CIP tasks include:

- Personnel: engineering, manufacturing, testing, quality control, and management
- Facilities: laboratories, test cells and test rigs for parts, components and engines, and manufacturing plant and tools for parts and engines.

CIP retains a design team, maintains a data base, and plans and integrates longer-range objectives for the engine program over its lifetime. The experience of engine companies in R&D technology and full-scale development programs augments CIP activities, and each has an effect on the other.

It is neither militarily nor economically sensible to attempt to find all engine problems during FSD. There is a need to continue aircraft turbine engine maturation during the entire operational life of an engine.

The military services seek a balance between FSD and CIP to allow the engine to be produced and fielded at some reasonable cost and time so that war-fighting capability can be enhanced and mission-oriented flight experience can be gained. Aircraft turbine engines are not fully mature when they enter operational service:

- Development time and cost are usually constrained so that only limited ground and flight testing are accomplished. Thus, not all failure modes of the engine have been uncovered by the time it enters operational service. Over the past four decades, significant improvements have been achieved in developing engines to higher life requirements. Accelerated mission testing is one new element of the improved FSD process. However, ground test simulations of flight conditions are not exact and design techniques for durability are not precise. To attempt to find all problems prior to operational use would be very costly and lengthy, with obsolescing technology finally reaching the field. FSD and CIP efforts need to be balanced to achieve engine maturation most efficiently.
- Some problems can only be found through considerable flight experience. Operational use is usually somewhat different than the original design allowed, and missions change during the life of the engine in response to threat changes and new applications.
- An engine is often "pushed" to its technological limits because demanding the most out of an engine will often provide higher capability and/or lower life cycle cost for the aircraft system (even though the engine will cost more to achieve the higher performance).
- There is a mismatch between the relatively shorter time required to develop and field a new airframe and the longer time to develop and field a new engine.
- Continuing maturation is necessary in the earlier years to solve safety-of-flight problems, to correct service-revealed deficiencies, and to reduce the life cycle cost of the engine during its time in the inventory; in the mid-years to increase durability, reliability, and maintainability; and in the later years to retain performance and improve repairability as the engine ages.

CIP funds a much narrower range of objectives today. CIP now funds only problems relating to safety of flight, correction of deficiencies, and life cycle cost improvements, whereas past policies had allowed funding of prototypes, performance growth versions of engines, and tailoring engines for new applications. All of these latter activities now have their own program elements in the R&D budget.

Important engine programs in all of the services are expected to be maintained in the inventory for 35 to 50 years. Since there are fewer new engine program starts today and the engine life cycle is longer than usually hypothesized in life cycle trade-off studies, there is even more reason for improving existing engines. In summary, the need for CIP continues today even though the engines coming out of the development process are more mature than they were in the past.

2. The Value of CIP

CIP has been a significant but declining cost to the military services. Since the beginning of CIP in the 1950s, the amount of CIP funding for engine maturation has declined substantially, largely due to improvements in the engine full scale development process and to the elimination of performance growth and new application objectives from CIP.

Over an engine's life cycle, the cost of CIP has sometimes exceeded the cost of developing the engine. The military services seek a balance between development and CIP costs, which are affected by the physical size of the engine (thrust), its operational environment (Mach number), its technology level, the "push" of the technology relative to the state of the art, and the duration and composition of FSD. Figure I-1 presents CIP costs for generations of tactical fighter engines relative to their full scale development costs. Later generations of engines are requiring less CIP relative to FSD costs; FSD costs themselves may be somewhat higher for later engines of similar characteristics because of the addition of time to accomplish accelerated mission testing. Improvements have been obtained in the full scale development process through more and better accelerated mission testing and in the CIP process by focusing expenditures on operational problems for the specific engine and not allowing the funding to be used for performance growth, prototyping or new applications. Further, the regulations governing when CIP can be started have changed over the decades.

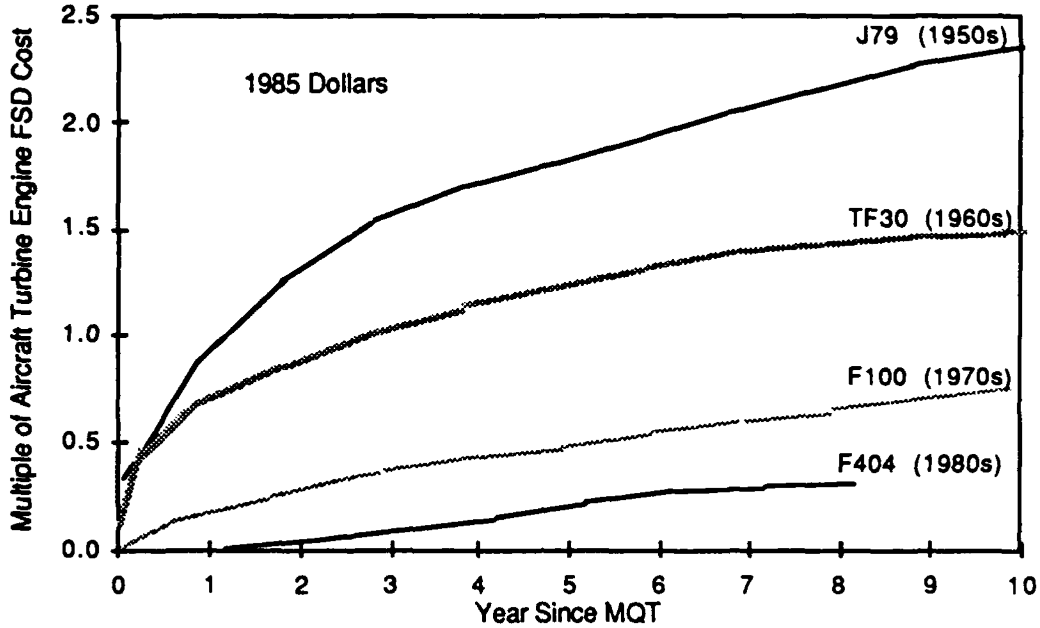


Figure I-1. Cumulative CIP Funding as a Multiple of Full Scale Development Cost: Four Tactical Fighter Engines

CIP is cost-effective. Under conservative ground rules – constant 1985 dollars and 10 percent discount rate – cost savings obtained from CIP significantly outweigh CIP costs, particularly when examined in the light of the longer life cycle of the engines in the inventory.

These savings are the result of (1) quickly solving safety-of-flight problems, which reduces aircraft attrition, (2) correcting service-revealed deficiencies, which reduces unscheduled engine removals and the spare engines and parts required in the field, and (3) extending the depot visit interval, which reduces operating and support costs.

A comparison of two examples is presented in Figure I-2. (See Section III for a full discussion of the analysis.) The J79 tactical fighter engine of the 1950s and the F100 tactical fighter engine of the 1970s are shown. The J79 was a technically advanced engine when it became operational in 1956; it is still in the military inventory 30 years later. The F100 engine was also very advanced for its time when it became operational in the mid-1970s. CIP has proved to be of substantial value to the military services, particularly since important engines like the J79 and F100 are expected to remain in the inventory for 35-50 years. Similar findings are true for other fighter, attack, bomber, transport, tanker and helicopter engines examined in this study.

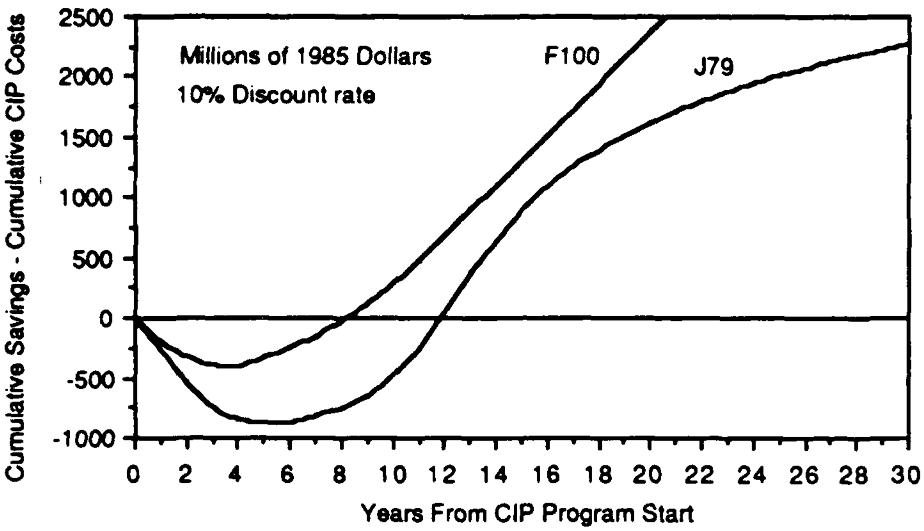


Figure I-2. J79 and F100 CIP Net Cost Savings: Depot, Attrition and Spares

We experienced difficulty in obtaining certain data suited to our analyses. Further, we had to rely on a life cycle cost method that was developed before the introduction of the newer design and maintenance practices.

The military services have difficulty in determining efficient CIP funding levels (and allocations to individual programs) when faced with annual funding decisions. CIP managers need better data and analytical techniques in order to relate improvements in the field to the costs to obtain those improvements.

CIP managers base their requests on future-oriented projections of cost savings (determined by accounting models) which may or may not be realized. More historically oriented analyses (using parametric models) of what has been accomplished by CIP over the years would be useful in providing additional information for their requests.

3. Policy Options for CIP

It does not appear to be practical to "gradually transition [CIP] financial support to the private sector" for all aircraft turbine engine programs in all mission areas; however, it might be appropriate to consider privatization in certain mission areas in which the commercial market leads. Direct funding of CIP in the military services has provided the direction, control, accountability, flexibility and response time that DoD needs, and the visibility into the use of funds that the Congress needs. Transitioning CIP to the private sector as a general rule would certainly be viewed with great concern by the DoD.

The evidence in this study strongly suggests not "privatizing" CIP for fighter/attack and bomber engines. These engines often set the technological limits of design capabilities and have only military applications. Uncertainty exists as to engine usage in the mission prior to operational use, and the time and money available for full scale development do not allow sufficient ground and flight testing to find all of the problems prior to operational introduction. Where the military is the only customer, the engine company can only recover costs from the government. Without CIP the government would pay the costs in some other, less visible way. Meanwhile, the military services would lose the direction, control and visibility of any efforts the engine company undertakes.

Consideration might be given to the possibility of restructuring warranties to create incentives for the engine companies to continue engineering support throughout the engine life cycle. Substantial modifications to commercial and military practice would be needed in order to provide the incentives to align company and military priorities under privatization. These could include incentive contracts or longer warranties that reward or penalize on the basis of performance, durability, reliability, maintainability, or availability targets, such as a target engine removal rate. However, attempts to create incentives for contractors have natural limits: the services put war-fighting capability first and efficiency second, whereas contractors work for their own survival and for maximum sales and profits. These modifications to current practices would require major changes in both CIP and other DoD policies.

In the case of transports and tankers, particularly when the military is adapting a commercial engine, it may be sensible for the military not to fund CIP or to fund only a minimal CIP program, and to take advantage of the benefits to a commercial engine program customer. This was done for the CF6 engine in the KC-10 aircraft where the military customer is one among many. At the present time, the F108 (CFM56) engine in the KC-135R program is being purchased under commercial ground rules, and soon the F117 (PW2040) engine in the C-17 program will be. The F108 has provided funds for CIP in the selling price of the first 1100 engines. Therefore, these two military programs (F108 and F117) should be monitored carefully for the insights they can provide as the Air Force becomes the principal customer.

There are helicopter engines in the inventories of the military services that fall into both classes discussed above, engines with solely military application and those in which the commercial market leads. They need to be examined on a case-by-case basis.

The reasons why the military might want to fund CIP directly when the military leads and at least a skeleton program when the commercial market leads include:

- Engine company attention to unique problems of military operations
- Change in company market and business strategy as the military service becomes the principal customer
- Limited warranty coverage
- Purchase of parts after the warranty expires
- Data rights.

In commercial practice, the selling price of an engine includes allowances for development amortization, engineering support services and warranty coverage. But warranties are really a form of short-term insurance. They do not at present cover the life of an engine. For the F108 and F117 engine programs for example, the Air Force will eventually need to buy large quantities of spare parts at commercial prices, and the company that developed the engine will be the only supplier. The company may change its marketing and business strategy because of the large volume of military business in a commercial program. Company priorities take the place of military priorities because in the commercial sector the engine company has direction of engineering support services and controls the engine configuration.

Commercial airlines have more leverage with engine companies in negotiating follow-on parts purchases from engine companies than the government does: the company's desire to maintain a good reputation with its customers; the airlines' ability to cancel purchase options; and the airlines' ability to penalize poor performance by not buying from that company the next time they are in the market (essentially "blacklisting" them). The military services do not have these options. Further, in the commercial engine market there are many customers, and the engine companies never know for sure when the next orders will come. There is intense competition, and the engine companies always want to show that they are responsive to their customers. They want to show that they have improved their product, they have the best or lowest cost product, and they respond to airline problems. This helps the airline position. However, evidence indicates engine companies may not always be responsive to all problems at all airlines; generic problems across all airlines receive attention while particular problems at individual airlines may not.

The retention of data rights by the military services has been a point of contention in competition. The military services own the data rights for engines where they fund development, but it is not clear what happens to these data rights when a company uses its own money to change the design of a military engine part to improve it. This issue has implications for competing parts in production. Its resolution would require attention to the language in contracts for programs where this issue might arise.

There are circumstances in which the military services might achieve competition for CIP funding.

The key issue in competing CIP is availability of sources. We examined possibilities for competing the entire CIP program, for competing certain functions like testing, and for competing individual CIP tasks. For current engines, competing an entire CIP program is not possible, because only the engine developer has the expertise to carry out the whole program. CIP for a particular engine might be competed as one element in a competitive production contract for that particular engine (e.g., Air Force F100/F110 alternate fighter engine programs could compete their respective CIP programs as a contract line item similarly to the way warranties were addressed). In the future, teaming in development could provide opportunities to compete all CIP (e.g., Army T800 program).

Competition for CIP testing is feasible and should be examined further. Several engine manufacturers have test facilities available. However, the costs and benefits of competing CIP testing need to be carefully examined.

Where there is competition in the engine acquisition program, competition for individual CIP tasks may be feasible and should be considered. The circumstances and the environment must be appropriate to accomplish a cost-effective competition. It does not make sense to establish a second source for competition, if the added cost and time lag are such that they cannot be recaptured within the framework of the competition. Moreover, the segmentation of CIP efforts would significantly increase the difficulty of integrating task efforts and planning longer-range improvements, not to mention the administrative burden to compete, negotiate, and monitor additional contracts. The services have opportunities to compete certain CIP tasks for the Navy F404 production dual sourcing, and later for the Army T800 program.

Other approaches to achieving CIP objectives as practiced for airframe and avionics equipment do not provide the flexibility and response time that CIP provides for engine programs.

Procedures used in airframe and avionics engineering support activities were examined to see if they presented a good alternative to CIP. In general, CIP has advantages that these other processes do not have: flexibility, quick response to more immediate problems, and the ability to plan longer-term improvements within a continuing engineering, testing, and manufacturing effort.

In summary, the government has pursued several strategies to ensure that, with multiple sources for CIP not available, the program is run in a cost-effective manner. Each company screens and evaluates tasks in proposing to obtain CIP support. There is competition within the R&D budget of the military service to get the CIP funding, and there is competition among companies' proposals and tasks in the allocation of available CIP funds by the military service. The services try to allocate funds to give the government the highest return on its investments in CIP.

The current programs have provided the insights that have led to the findings and recommendations of this study. Table I-1 summarizes possibilities for privatization and for competition within CIP. CIP is cost-effective, but more importantly it has served the military services' principal objective of enhancing war-fighting capability. It does not at this time appear to present a problem that needs drastic change. There is always the possibility of doing better under another policy; there is also the possibility of doing worse. The most opportune time to consider alternatives is when formulating the acquisition strategy for a particular engine program. Even then, caution should be exercised in examining opportunities.

Table I-1. Summary of Selected Current and New Engine Programs: Possibilities for Privatization and Competition

Mission Area	Program/Engine	Privatization Candidate	Compete Within Engine CIP Candidate
Strategic			
• Bomber	B-1B/F101	No	No
	NEW PROGRAM	No***	Yes*
• Tanker	KC-135R/F108 (CFM56)	Yes	No**
	NEW PROGRAM	Yes	Yes
Tactical			
• Fighter/Attack	F-4/J79	No	No
	A-6/J52	No	No
	F-111/TF30	No	No
	A-7/TF41	No	No
	F-14/TF30	No	No
	F-15/F100; F110	No	No*
	A-10/TF34	No	No
	F-16/F100;F110	No	No
	F/A-18/F404	No	Yes**
	NEW PROGRAM	No***	Yes*
• Helicopters	UH-1, AH-1/T53	No	No
	CH-47/T55	No	No
	OH-6, OH-58/T63	Yes	No
	UH-60/T700	No	No
	AH-64/T700	No	No
	NEW PROGRAM	No***	Yes*
Airlift	C-141/TF33	No	No
	C-5A/B/TF39	No	No
	C-17/F117 (PW 2040)	Yes	No
	NEW PROGRAM	Yes	Yes*
Support	C-9/JT8D	Yes	No
	T-39/J60- JT12)	Yes	No
	TTBTS	Yes	No
	NEW PROGRAM	Yes	No

*Opportunities would occur where development teaming and/or production dual sourcing are an element of the system acquisition strategy.

**Possibilities for competing CIP as a total package may be enhanced by future competitive acquisition.

***Privatization would require major changes in acquisition strategy.

C. RECOMMENDATIONS

We recommend that–

- OSD and the Congress retain CIP in its present form; keep CIP funding separate from any prototyping, performance growth, or new applications for existing engines. Congress might consider returning part of CIP to the procurement account if RDT&E competition for funding becomes detrimental to long-range CIP efforts.
- OSD and the Air Force monitor privatization results carefully for the F108 and F117 engine programs to obtain insights into the behavior of the engine companies as the military service becomes the principal customer and the market structure changes.
- The military services investigate the costs and benefits of competing CIP as a total program or in part as one element of an acquisition strategy when considering a new aircraft. The F100/F110 competition, the F404 dual sourcing, and the T800 joint development are current procurement or development programs which might have possibilities. The military services should also investigate competing CIP tasks or functions within a CIP engine program (FADEC fuel control for the F404 or accelerated mission testing for several programs).
- OSD and the military services develop and maintain an aircraft turbine engine data base that reflects life cycle cost concerns as well as management planning and scheduling. Consistent formats and definitions need to be developed by OSD and the services for important data elements, particularly where the O&S process is different among the military services.
- OSD and the military services develop a new parametric LCC model for aircraft turbine engines with which to perform historical and future cost-savings analyses to augment such analyses done by the military services and industry today with future-oriented accounting models. The model will need to accommodate modular engine design and on-condition maintenance practices. Further, base level costs, which are now more important with these new design and maintenance practices, will need to receive more attention in the operating and support cost component of LCC.

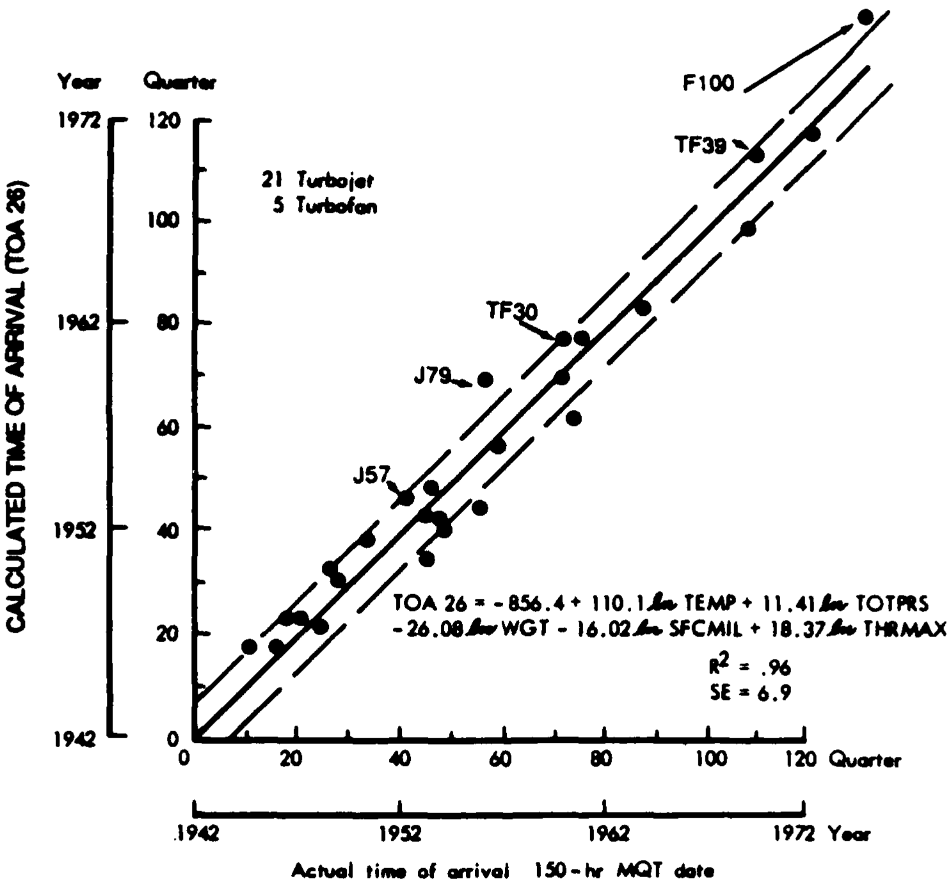
II. THE ROLE OF CIP

Periodically, questions about military CIP arise: What is CIP? Why is it needed? What does it accomplish? In response to these questions we present a discussion of the role of CIP in the life cycle of aircraft turbine engines. In order to understand CIP better, we first discuss the development and maturation of these engines. This is followed by a discussion of the objectives and functions of CIP, and the resources required to accomplish CIP tasks. Then the history of CIP during the past four decades is presented. Finally, we describe how the CIP process works today in the military services and in industry. Since commercial practice and airline experience are somewhat analogous to transitioning military CIP to the private sector, a comparison between military and commercial practice is presented.

A. DEVELOPMENT AND MATURATION OF AIRCRAFT TURBINE ENGINES

When the engine and the other system components achieve production status and go into operational service, the engine full scale development (FSD) program has not at that time provided enough ground and flight testing to insure that all problems have surfaced and been solved. Ground testing can only simulate the expected environment; flight testing begins to discover operational problems. If the engine were required to achieve a high level of maturation during FSD, the effort would be enormously expensive and time-consuming while delaying the introduction of the new technology in the operational forces. In addition, changes in requirements or in operational use affect the engine's early maturation as it enters service and pilots discover its operational capability. Some type of continuing engineering support is required after the engine enters operational use in order to discover and correct problems before they have a drastic effect on operational capability, availability, and readiness. Operational experience is fed back into the Component Improvement Program and later considered for the next generation of aircraft.

Sometimes new engines embody large technical leaps, and can be expected to present still other operational problems after their introduction. Figure II-1 presents results of a method that was developed to assess quantitatively the trend of aircraft turbine engine technology. The model comprises data for 26 engines developed over the three decades from 1942 when the first aircraft turbine engine flew in the United States until 1972 when the F100 engine was being developed for the F-15 aircraft.[1] The figure shows when engines passed their qualification test relative to the date they were expected to pass, calculated from the performance characteristics sought. The F100 engine is depicted as a very advanced engine for its time as was the J79 in the mid-1950s. Because of this "pushing" of technology during full scale development, some engines tend to be more immature when they reach service and thus require greater continuing support.



Source: Nelson (1977).

Figure II-1. Military Turbine Engine Time of Arrival

[1]See Nelson (1977) for discussion of this method.

The engine development and maturation process is depicted in Figure II-2. R&D technologies, new concepts, hardware prototypes, full scale development, and CIP are shown as they flow into new engines, performance growth engines, and existing engines.

When an airframe and an engine are started together, the engine is not so far along in its development as the airframe at the time the airframe is ready for operational use. There have been efforts in the past to start engine programs prior to aircraft programs, but it is difficult to begin an engine development that does not have a specific intended application, and so prototypes have been able to start perhaps only one to two years prior to the full scale development start of the airframe.[2] This mismatch between airframe and engine schedules is portrayed in Figure II-3. Airframes can be developed in 4-6 years, whereas engines take 6-8 years.

There have been efforts recently to improve early maturation of the engine through more and better developmental testing, in particular adding accelerated mission testing (AMT) to development. This also has the effect of increasing the engine schedule and perhaps moving IOC later to accommodate the engine and help to correct the mismatch. The accelerated mission testing and lead-the-force testing in operational service discover problems before they become critical to the entire fleet of operational aircraft.

Improvements in the engine development process over the years are summarized below.

- 1952 - Life increased from 10-25 in 1946 to over 100 hours
- 1969 - Improved criteria on structural durability applied to F101 and TF34 programs
- 1973-74 - specification updated (MIL-SPEC 5007D)
- 1975 - Navy "New Look" development concept applied to F404 engine
- 1976 - Air Force Scientific Advisory Board review
- 1978 - USAF ENSIP developed
- 1979 - USAF durability & damage tolerance assessment on F100
- 1982 - USAF ENSIP MIL prime specification
- 1985 - Navy streamlining of development process and specifications (examining MIL-SPEC 5007E and USAF MIL prime spec)

[2]The last engine that started development without an application was the T64 in the late 1950s.

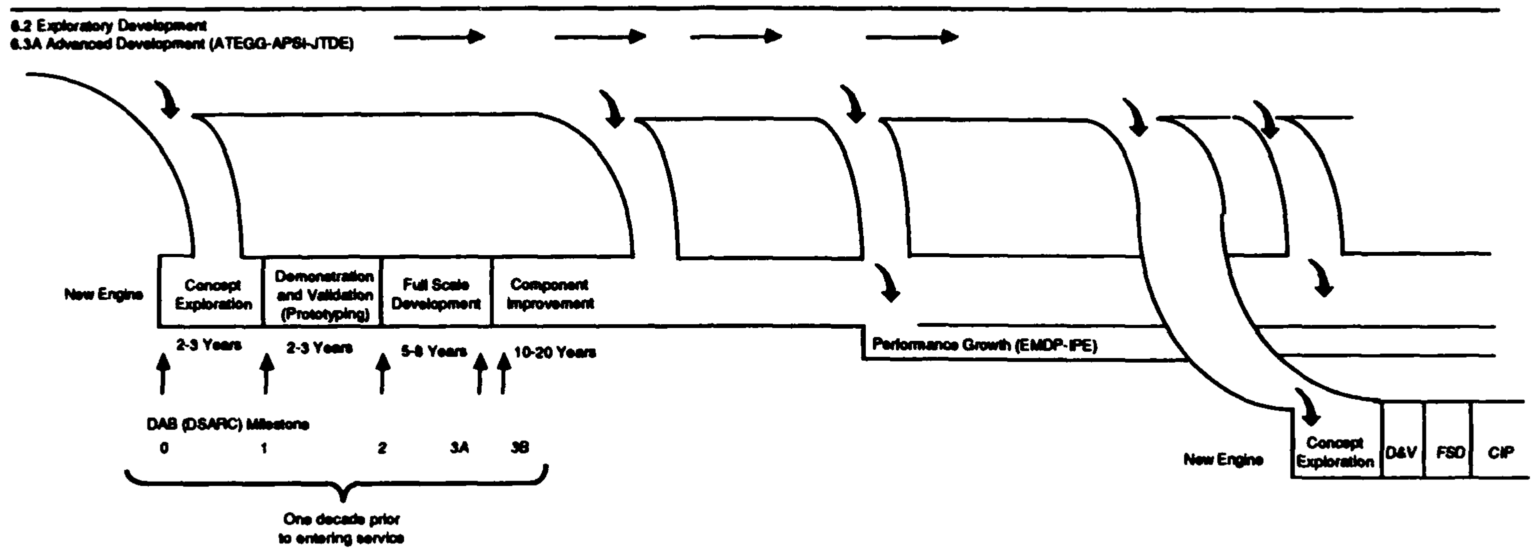


Figure II-2. Aircraft Turbine Engine Technology, Development and Maturation

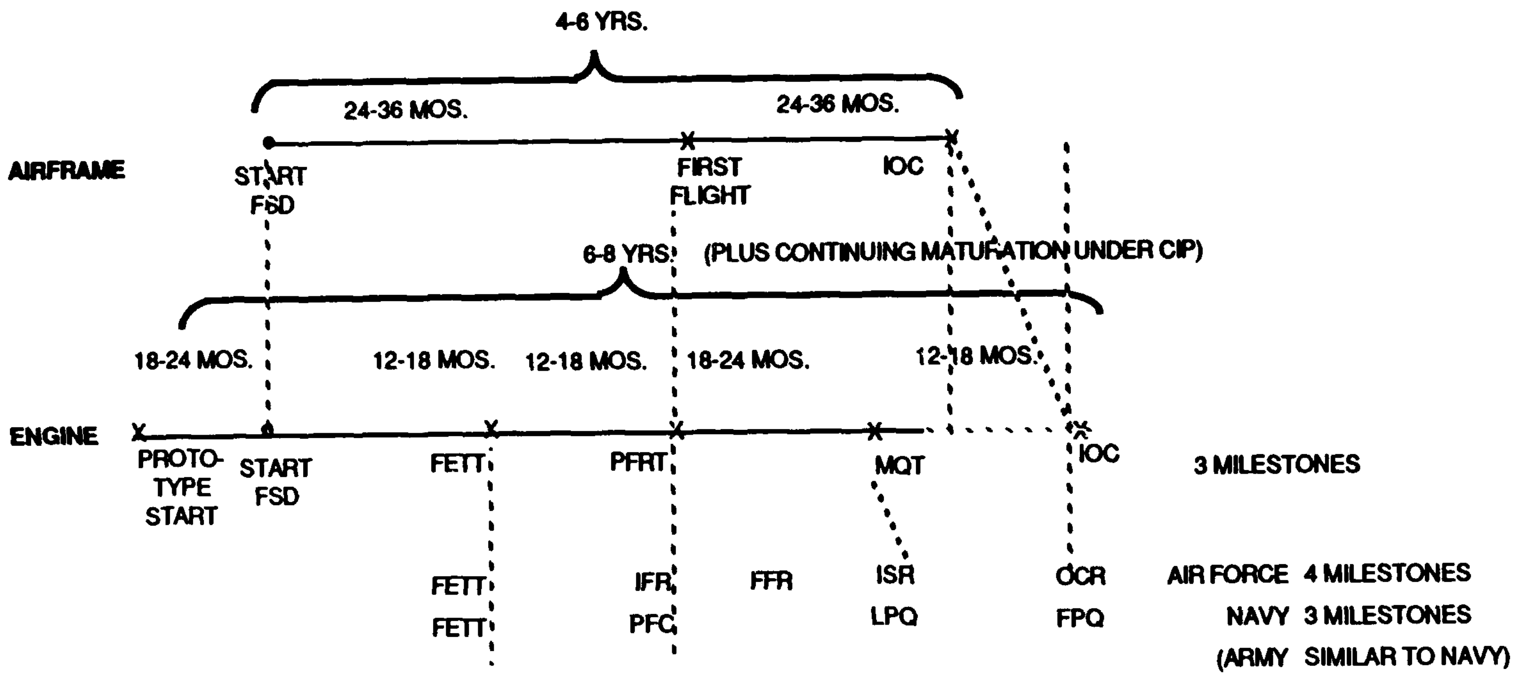


Figure II-3. Airframe and Engine Development Schedule Mismatch

Besides the changes in the development process with regard to the milestones, additional testing, and lead-the-force, there have also been changes in operational procedures. In particular, aircraft engines are now monitored in flight and those data are used for the early detection of failure modes. Also, new design features and repair practices have been incorporated, such as modular design, on-condition maintenance (OCM), and ease of removal, to make it easier to keep the aircraft in service with spares.

Table II-1 presents important engine programs over the past 30 years. Expected program life cycles are 35 to 50 years. Engines with multiple applications in particular tend to remain in the inventory longer. Also of interest, production periods range from three to thirty years, while out-of-production engines remain in active service for up to a quarter of a century beyond the last production delivery.

An engine begins operational service with less than 20,000 test hours of experience, mostly on the ground. Over its lifetime a useful engine will complete millions of flight hours, so this early experience usually represents much less than one percent of its lifetime experience. The environmental effects on the aircraft and engine are not well understood at this point and the mission usage may change over time as the operational forces come to understand the system's capability.

Although the improvements mentioned above have reduced the scale of CIP (see Section III), the balance between development cost and time, the innovations in technology, the long life of engines, and the varying operational requirements make it likely that continuing engineering support for engine programs is still needed.

B. MILITARY CIP

1. History

There have been many studies of the aircraft turbine engine development process and CIP over the past several decades. Recommendations have been made, and changes have improved the development process and CIP. For the most part, the trend in the CIP changes has been toward more direction and control by the military and higher visibility of the funds on the part of the military and Congress. Table II-2 presents a history of CIP from the 1940s to the 1980s.

Table II- 1. Engine Programs Historical Data – U.S. Military
(As of the end of 1986)

Engine Program	Development Start (Year)	Production Start (Year)	Production End (Year)	Production Duration (Years)	Quantity Produced	Quantity Active	EFH Cum (Mil)	Life Cycle Duration Expected (Years)	Aircraft Application(s)
J52	1952	1960	(P)	26	3537	2201	8.8	40	A-4/A-6/EA-6
J57	1947	1953	1964	12	14057	6266	85.4	45	Many
J75	1953	1957	1959	3	1469	442	3.3	35	F-105/F106
J79	1953	1957	1979	23	13683	8270	26.1	45	F104/B-58/F-4
J85	1954	1957	1987	30	12212	9850	36.0	40	T-38/F-5
TF30	1959	1965	1986	21	3483	2 512	3.9	40	F-111/F-14/A-7
TF33	1957	1960	1984	24	2978	3419[1]	43.2	40	B-52/C-141
TF34	1968	1971	1983	14	2127	1900	4.8	35	S-3/A-10
TF39	1965	1967 1985	1971 (P)	4 (P)	539	531	3.25	45	C-5A/B
TF41	1966	1969	1983	14	1414	1098	3.25	35	A-7
F100	1968	1974	(P)	(P)	4775	4332	4.4	40	F-15/F-16
F101	1970	1983	(P)	(P)	296	296	0.011	40	B-1
F110	1979	1985	(P)	(P)	171	171	0.002	35	F-15/F-16
F404	1975	1980	(P)	(P)	1411	1344	0.65	35	F/A-18/A-6
T53	1952	1959	(P)	(P)	14779	10505	29.6	45	UH-1/AH-1
T55	1958	1961	(P)	(P)	2548	2226	3.7	40	CH-47
T56	1950	1953	(P)	(P)	12082	11058	116.0	50	C-130/P-3/E-2
T58	1953	1956	(P)	(P)	5506	3885	14.5	40	SH-2/SH-3/CH-46
T63	1960	1963	(P)	(P)	4795	3038	8.8	50	OH-6/OH-58
T64	1960	1963	(P)	30+	2547	1265	3.5	40	CH53
T700	1972	1978	(P)	(P)	3256	2700	1.0	40	UH-60/AH-64

[1] Includes modified JT3D. (P) = In production.

Table II-2. CIP History

	Late 1940s	1950s	Early 1960s	Late 1960s	Early 1970s	Late 1970s	Early 1980s (Now)
Policy	Contractor responsible for engineering support	Established CIP line when large volume production in Korean War resulted in large payments to engine companies. Set up engine advisory group of government people to direct and control effort (mid-1950s).	Obtain support from all users - FMS and commercial derivatives contributions included.	Reduce indirect funding Stop growth/ derivative engine development.	Require equitable foreign funds to share CIP support as condition of sale	Define CIP as R&M, and SRD. Start CIP at delivery of first production aircraft.	Congress moved CIP into R&D account Desire to compete CIP Provide more R&D effort Compete production engines
Funding Sources	Included in price of engine (Indirect funding)	Direct production funding.	Direct and indirect production funds.	Direct and indirect funding Contractor support from commercial derivatives	Direct and indirect production funds and commercial contributions	Eliminate indirect funding only direct production funds, FMS funds and commercial derivative funds.	RDT&E account
Advantages	Small number of engines produced Therefore small number of government personnel	Government started to direct and control CIP effort and funding level. Funding visible to Congress.	Spread cost more equitably across all users	Government controls efforts and sets priorities on contracts	More equitable sharing of CIP.	Clear visibility of funding, reasonably covered in production accounts.	Maintains government direction, control, and visibility.
Disadvantages	No direct government control Contractor determined what work was to be done. Funds not visible to Congress.	Increase in government personnel.	Congress did not have control or visibility of total funding	More reviews of element funding Difficult to support out-of production engines.		Starting CIP at first production aircraft delays efforts on problems discovered in flight test and qual tests. Additional funding source required between qual and first aircraft delivery not timely and difficult to obtain.	Must compete for R&D funds each year. Competition for R&D funds high. Identifying tasks in detail difficult. Difficult to quantify impacts of arbitrary reductions.

In the 1940s, product improvements for engines were funded through an add-on to the production selling price of engines and parts to obtain the engineering support services needed. This money was used to "start" new programs by building prototypes as well as to grow existing engines, to apply existing engines to new aircraft, and to accomplish the objectives normally associated with CIP cited above. Also new applications were funded with this money. Because of the high volumes of engines produced during the Korean War, large amounts of money were funnelled to the contractors through this add-on to selling price. The government had little control of or visibility into how this money was being spent, and so in the mid-1950s, CIP was created specifically to obtain direction, control, and visibility of the funds. Over the years, additional limitations were placed on what CIP could do. New engine "prototype" programs could not be started with CIP, performance growth of existing engines was prohibited, and any additional applications of an engine were funded under the specific program involved. All of these activities went into separate R&D program elements.

Over this four-decade period, there have been variations in the mixes of direct contract funds, indirect funds, contributions from foreign military sales, contributions from contractors because they developed and sold commercial derivatives of military engines, and other support funds provided for military service activities, such as the use of test facilities at Trenton for the Navy or at Tullahoma for the Air Force. Also the funding category varied. For most of the time, the funding was in the procurement account. At one point, the operations and maintenance account was used by the Air Force, for example, when out-of-production engines were transferred to the Air Force Logistics Command and there was no other source of funds to carry on that activity. When all engine responsibility was transferred back to the Air Force Systems Command with the creation of the Propulsion Program Office in the Aeronautical Systems Division in the late 1970s, all CIP was funded from the production accounts until Congress directed that all CIP activity be funded under R&D in 1980. There is now an RDT&E program element for each military service for CIP. The funds are allocated by each service for the engine programs that are their responsibility. Arrangements are made to jointly fund engine programs that are in more then one military service with the principal user retaining contracting responsibility. Now, in the 1980s, consideration is once again being given to the options for managing and funding CIP.

2. Objectives, Functions, and Resources

CIP objectives, functions, and required resources are listed below.

- Objectives

  To correct
  - Safety of flight problems
  - Service-revealed deficiencies in operational use
  - Failures induced early in accelerated mission ttesting and lead-the-force operations

  To improve
  - Durability
  - Reliability
  - Maintainability
  - Producibility
  - Repairability

  To reduce
  - Parts cost
  - Engine cost
  - Life cycle cost (including fuel cost)

  To provide
  - Logistics Support Planning
  - Integration of total effort to obtain improvements
  - Opportunity for new technologies insertion

  To retain performance over engine lifetime in inventory

- Functions
  - Engineering analysis and design
  - Manufacture of parts for development testing
  - Testing of parts and engines
  - Quality control of parts and engines
  - Management/Integration of CIP program

- Resources Required

  Personnel
  - Engineering
  - Manufacturing
  - Testing
  - Quality control
  - Management

  Facilities
  - Laboratories
  - Test cells and test rigs for parts, components and engines
  - Manufacturing plant and tools for parts and engines

The services track the following measures in order to determine the support needed to meet the objectives:

- Class A accidents
- Aircraft mission readiness
- Aircraft Availability
- Engine unscheduled removal rates
- Engine mean time between failure
- Engine mean time to repair
- Engine depot visit rate
- Engine life cycle cost

First and foremost among objectives are safety of flight and correction of service-revealed deficiencies in early operational service. Solving these problems reduces the attrition rate of aircraft (Class A accidents) and the grounding of aircraft, and sometimes the grounding of entire fleets because of critical problems. The longer-term objective of CIP is to reduce life cycle cost by improving durability, reliability, maintainability, producibility, and repairability. Figure II-4 portrays a notional characterization of what CIP accomplishes over the longer term, in deepening and extending the "bathtub" shape of the traditional durability, reliability and maintainability measures per engine flying hour over the engine life cycle. In particular, extending the depot visit interval of engines and modules has a high payoff. Depot costs are the largest part of operating and support costs and an engine repair at the depot can cost as much as one-tenth to one-fifth of the engine price. An engine may be returned to the depot half a dozen to a dozen times in its life cycle (considering the longer life cycles of engines in the inventory today). Thus, it may cost more for depot overhaul than for procuring the engine initially. As an engine ages, effort is also needed to retain the performance of the hardware and to develop repair techniques.

In addition to these activities, CIP also provides logistics support planning, integration of the total CIP effort concerning the tasks that are being worked on from year to year to obtain improvements in major components, and also provides the opportunity for inserting new technology into the engine on a limited basis. This experience provides engineers with added confidence that these new techniques and new materials are sufficiently mature to introduce on a broader scale into the next generation of engines.

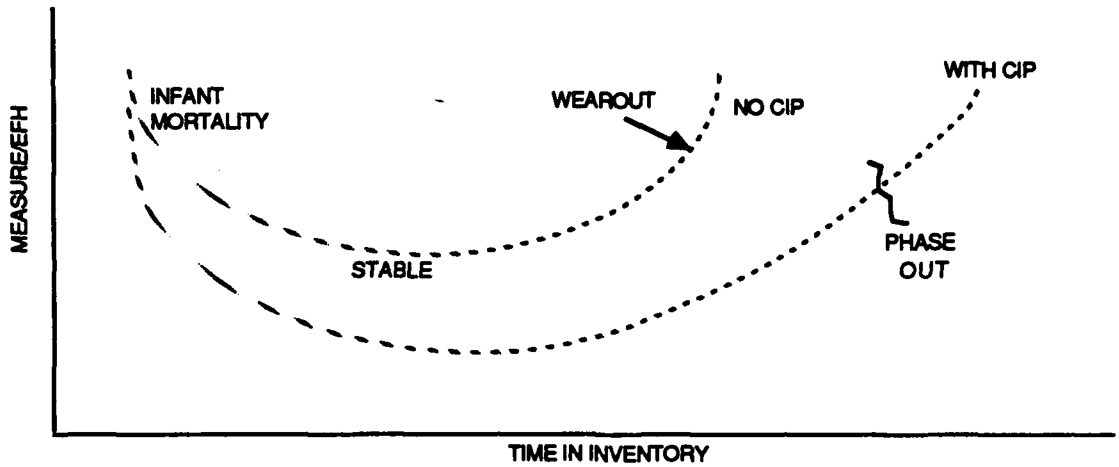


Figure II-4. Measures/EFH and Time in Inventory

CIP requires a mix of engineering, testing, manufacturing, quality control and management functions. Engineering design is critical on a continuing basis, and CIP maintains the design team and the corporate memory that was gathered during development and keeps that expertise available throughout the life cycle. Usually engineering and testing represent the largest portion of CIP activity. Occasionally, however, there will be a large manufacturing cost if additional test engines are required for a particular major component improvement such as as a new compressor or turbine, or a core comprising the compressor, combustor, and turbine. The range of percent of effort is displayed below by function and by objective.

Function	Percent of Effort
Engineering	25-50
Manufacturing	5-40
Testing	15-50
Quality control	5-10
Management/integration	10-20
Objective	
Flight safety	5-40
Service-revealed deficiencies10-30	
Durability, reliability, maintainability	30-50
Producibility and repairability	10-20
Management/administration/integration	10-20

The resources required for CIP represent the skills of personnel in the areas of engineering, testing, manufacturing, quality control and management, and government and industry investments in facilities and laboratories for testing and manufacturing. Expertise is built up over many years of experience with R&D technology programs, full scale development and production programs, and CIP activities. Within major engine CIP programs, perhaps several hundred engineers are funded, but the body of work may be accomplished by tapping a pool of several thousand engineers. A major engine program will require the support of extensive laboratory testing and manufacturing facilities. Such investments can represent tens to hundreds of millions of dollars on the part of the government and the company. With regard to resources, a major program may require anywhere from 5 to 15 engines and conduct from 1,000 to 6,000 hours of testing each year depending upon the size of the program and the stage of improvement of the engine. Table II-3 presents examples of resources needed for large, medium, and small CIP efforts. These data were aggregated from responses to questionnaires sent to five U.S. engine companies–Allison, Avco-Lycoming, Garrett, General Electric, and Pratt & Whitney.

New applications and different use of an existing engine can create new problems. Any change in the operating environment can also bring additional problems. As the engine matures and phases out of production, a new set of problems can arise with regard to wearout. Thus, there can be a different focus to the problems being addressed at each stage of an engine life cycle. Problems do continue to arise throughout the life cycle of the engine. Very early in its maturity, the concerns are safety of flight and correction of service-revealed deficiencies. As these are overcome, the emphasis shifts to lowering life cycle cost; and as the engine begins to approach the end of its life cycle, concerns are wearout and obsolescence and retaining performance.

3. CIP Process

The military services develop a CIP program for a particular engine on the basis of experiences with other engine programs and expectations that they have for that engine over its operational life. A long-range plan is developed, allowing flexibility to deal with immediate safety and operational deficiency problems. CIP support is allocated to each program by considering how many engines there will be in the inventory, what applications the engine will fulfill, and how long the engine is expected to remain in the inventory.

Table II-3. Resources Supporting CIP Activities

Program Size (CIP $ Annual Funding)	Technology Base Annual Funding ($)	Test Engines	Test Hours Per Year	Engineers Per Year	Investment in Lab. Manuf. Test Facilities ($)
Large Program (Early in Maturation) (25M-100M)	100's M	5-15	1000-6000	100-500 (from pool of 500-5000)	500M +
Medium Program (Stable) (2M-25M)	25–100M	2-5	100-1000	10-100 (from pool of 50-500)	100M
Small Program (Out-of-Production) (Less than 2M - usually less than 1M)	1–25M	1-2	0-100	5-10 (from pool of 50–100)	10M

Note: The pool represents the number participating in FSD who are still expert on the particular engine.

The criteria that the military consider when they are determining the level of CIP support for a particular engine program each year are presented below. Immediate problems concerning critical deficiencies top the list. The mission area, applications, flying program, inventory, and life cycle establish the priority of the engine to the service. The effects of CIP efforts on life cycle cost are evaluated. Consideration is given to whether the engine is still in production, how long it may stay in production, or whether it is out-of-production and how long it will remain in the inventory. Short-term and long-term failure modes are considered, as well as opportunities for inserting new technologies such as improved materials or new design techniques.

Critical Deficiencies
- Safety /flight envelope/performance degradation
- System availability and operational requirements

Mission Area/Flying Program
- Priority
- Activity level

Inventory (or planned inventory)
- Number of engines/flying hours
- Number of different applications during life cycle

Effects on Life Cycle Cost (return on investment)
- Aircraft attrition
- Whole spare engines and modules
- Depot visit interval
- Parts cost
- Labor cost

Time in Service
- In production vs. out-of-production support (longer-term failure and wearout modes)
- New-technology insertion

The CIP process is described in Table II-4. On the basis of experience in the field, knowledge of the engine design, and recollections of previous engine experience, the companies propose a program, develop a statement of work, and submit a priced proposal for the tasks involved. The military service selects the highest priority tasks from each of the various company programs and from among the different companies until they have exhausted the available funding, and then the military services and the companies execute the CIP program.

For a service to obtain funding, a request must pass through many points on its way to Congress. For example, in the Air Force, the Engine Advisory Group at the Aeronautical Systems Division, the Air Force Systems Command, the Air staff, DoD, and OMB review a request before it goes into the President's budget. The budget is transmitted to Congress, authorized and appropriated at some funding level which may be different from that requested (it could be higher as well as lower), and comes back down through the same offices. Just as likely on the way down as on the way up, and in Congress, portions of the money may be reduced or reprogrammed. In the recent past, the competition for RDT&E funds has become considerably more intense and reductions to the requests for CIP submitted by all the services and within the services have gotten substantially larger. Recent Air Force requests have been cut considerably. (The Army and the Navy exercise the same process in principle, but don't apply as high a priority to CIP at higher headquarters as the Air Force and therefore have suffered even larger reductions than the Air Force over the past few years.) Joint programs can also have funding problems if one service does not contribute its share.

During the process of selecting, funding and executing tasks, the company and the service examine field experience and coordinate with each other. They also obtain comments or suggestions from U.S. and overseas users and they conduct annual or semi-annual CIP reviews. In the current process, although the company proposes CIP projects, military priorities prevail; military and company priorities are not always the same, so military direction and control insure that military priorities will be uppermost.

Table II-4. CIP Process

Factors in Determining Candidate Tasks (Military Service – Company)	Planning and Coordination (Military Service – Company)	Proposals (Company)	Selection (Military Service)	Execution (Military Service – Company)
Review Field Incidents/Accidents Obtain User Inputs - Semi-annual reviews - Annual conference (incl. FMS) Examine Service MIS Inputs - UERs, MTBFs, MTTRs - Repair/overhaul records - Trends Review Company In-house Manufacture/Vendor Manufacture Problems Review AMT Test Results/ Maturity Assessment of Engine Consider On-going Tasks - What learned - Interactions/integration with new task(s) Review Base/Depot Repair Problems Consider Inventory/Applications	Establish Priorities - Safety of flight - Correction of service revealed defiencies - Life cycle cost reduction Perform Evaluations - Expected improvements in operating measures - Expected cost avoidance/ reduction - Economic analysis (ROI, breakeven) Maintain Long Range Plans Perform Management Reviews - Company - Military Service	Obtain RFP Develop SOW Develop Price	Obtain Funds Establish Criteria for Task Selection - Safety of flight - Correction of service revealed deficiencies - Life cycle cost reduction - Users concerns/changes in operational use - Inventory/applications - Engine maturity/remaining life - Engine production status - Technology insertion Evaluate Proposed Tasks for All Proposals Select Tasks from Companies Proposals Allocate Available Funds to Companies	Manage program Maintain feedback Monitor task progress Consider revisions to program to address immediate problems in field Develop ECPs for production and/or retrofit Maintain configuration control under service direction

C. COMMERCIAL ENGINE DEVELOPMENT AND MATURATION

The commercial aircraft turbine engine development and maturation process also requires a sustaining engineering component. It is very different from the military process with regard to how engineering support activities are funded and who directs and controls activities and tasks. It is important to consider the commercial engine process when examining the feasibility of transitioning CIP to the private sector because this commercial process can be considered a model or an analogue of privatized CIP. Company priorities now take the place of military priorities because in the commercial sector the engine company has direction of engineering support services and controls the engine configuration. Modifications to commercial practice would be needed in order to provide the incentives to align company and military priorities. The differences in military and commercial practices are displayed in Table II-5.

The airlines are the principal customers in commercial service. The decision process that an airline goes through in selecting a new engine includes consideration of company support, including engineering support. The airlines expect to pay the cost of the engineering services that are covered under direct contract in the military for CIP activities as part of the purchase price of engines and spare parts. The commercial price includes an allocation for engineering services and the airlines pay it not only in the engine price, but also in parts prices for the entire life cycle of the engine. There can be very dramatic markups of prices in the commercial sector on the order of 50-100 percent. These prices cover the services that are associated with engineering support, field representatives, and warranties. They also include recoupment of the company's development cost and launching cost, costs that arise from initial low sales prices to get the first customers to commit to the engine in order to "launch" production. It can take 10 to 15 years for the company to break even. The company directs the engineering support so its priorities are uppermost. It maintains configuration control of the engine which means it determines what the correct parts are for the engine at any given time and what stock will be available when someone wants to order parts.

The company also determines whether certain problems that are outside the warranty deserve its engineering support or not. The airline has some leverage regarding an engine company responding to a particular problem. The engine company's reputation with that airline and with the industry can be affected by the kind of service provided. An

Table II-5. Military/Commercial Market Comparison

	Military Programs	Commercial Programs
Direction, Control, and Visibility	*Customer (Army, Navy, Air Force)* - Directs work effort - Owns design, data rights - Controls configuration - Holds marketing rights - Sets profit level - Pays for development and improvement costs incrementally	*Contractor (Engine Company)* - Directs own work - Owns design, data rights - Controls configuration - Develops market and strategy - Sets pricing level based on market - Recoups development and improvement costs and program launching costs in sales revenues
Source of Funds for:		
• Engines	Procurement Contract	Customer Orders
• Spare Parts	Procurement Contract	Customer Orders
• Product Improvement	CIP contracts	Sales Revenues
• Warranty	Procurement Contract	Sales Revenues
• Engine Model Enhancements	EMDP Development Contracts, then CIP	Sales Revenues
• Technology Advancements	IR&D, Development Contracts, Discretionary	Sales Revenues, IR&D
• Development	Development contract	Sales Revenues, IR&D
• Overhaul	Customer or contractor accomplish	Airlines, engine company or third party accomplish
Business Approach:		
• Establishing Revenues	Costs established and "allowable" profit added through Government audit process	Prices established by market
• Allocation of Revenues	Segregated by engine model	Allocation across models at Contractor's discretion
• Business Base	Determined by Government - Competition (such as parts breakout) may lower cost, increase efficiency, and provide larger industrial base and may also lessen company sales base and shift company discretionary funds to nearer term considerations	Includes all sales, (no breakout)

airline could also threaten to cancel any further options for that particular equipment if it still has options for it. This would be a very drastic step to take since there is usually a wait of several years to obtain equipment and it might not have other prospects for obtaining new equipment at that moment. One other lever that airlines have is the threat of not ordering new equipment from that particular company the next time they are in the market (in essence "blacklisting" them). So the airline can hold past performance against a company. This is a difficult thing for the military services to do since by law they must consider all qualified bidders in a competition regardless of how they feel about past performance. They may weigh that factor in the selection process, but if they do not take the lowest cost bidder, and if there is a challenge to the decision, then the services will be required to defend the decision they made while the decision itself is held in abeyance and the program may be stalled for some period of time.

The commercial engine market is fractionated, and so engine companies never know for sure when the next orders will come and how big they will be. There is intense competition, and the engine companies always want to be ready to show that they are responsive to their customers. They want to show that they have improved their product, they have the most productive or lowest cost product, and they respond to airline problems. However, the engine company may not always be responsive to all problems at all airlines; generic problems across all airlines will receive attention, particular problems at individual airlines may not.

All of these considerations are of concern as we investigate the policy issues for CIP, but first we will examine the value of CIP to the military services.

III. THE VALUE OF CIP

This section examines the costs, benefits, and cost-effectiveness of past CIP efforts. CIP costs are presented in terms of the services' total annual CIP costs and the CIP costs associated with individual engine programs; normalized cost trends are presented for these selected programs. The benefits of CIP are described and quantitative measures are presented for representative engine models; included are parameters describing engine-related aircraft attrition, unscheduled engine removals, and depot visit rates. The cost-effectiveness of past CIP efforts is examined by quantifying as cost savings the benefits of CIP for past engine programs.

A. THE COST OF CIP

CIP represents a small, yet important portion of the RDT&E defense budget. For FY 1987 the RDT&E budget will be over 35 billion dollars, while CIP funding will total less than 150 million dollars. CIP represents less than half of one percent of the total RDT&E budget. Looking at this relationship at the service level, the Air Force's CIP program is most substantial at about one percent, the Navy's is at one half of one percent and the Army's is small. The Army has not placed as high a priority on CIP as the other services, but is reconsidering CIP for several older engines.

Many factors affect the level of CIP costs associated with engines in the services' active inventories and thereby the level of funding required by the services. Over the past two decades, there has been a downward trend in the Navy and Air Force's CIP funding. This is evident in Figure III-1, which shows this funding over time in constant FY 1985 dollars (Army funding is not included in the figure).

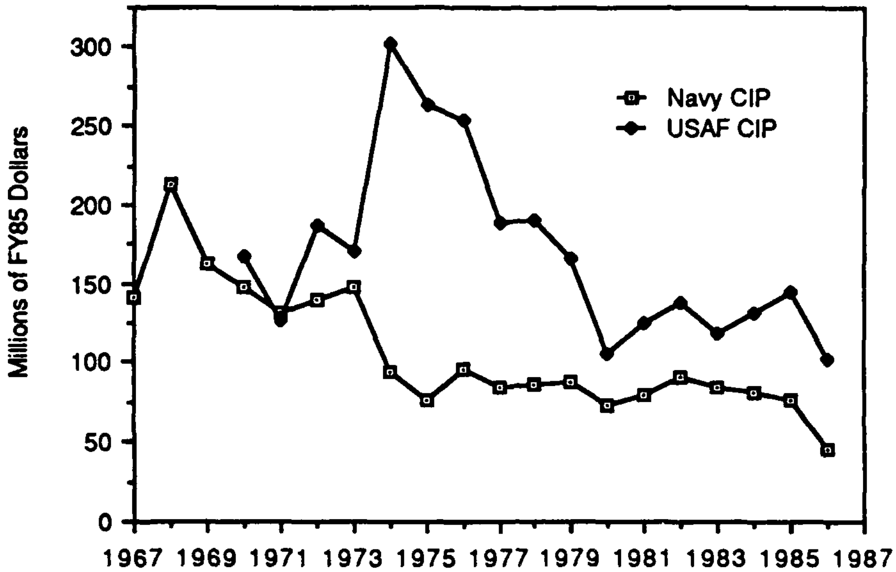


Figure III-1. Navy/USAF CIP Funding by Fiscal Year

Upward movements in funding levels can be partially explained by the addition of new engines to the inventory which require significant early CIP efforts. For example, the substantial spike in USAF funding in the mid-1970s can be explained by the introduction of the F100 engine in the F-15 aircraft. This engine was relatively immature when it entered operational service and thus required a substantial CIP effort in its early years. This was due in part to the technology "push" represented by this engine. A much smaller increase in USAF funding in 1983-1985 is related to the introduction of the F101(B-1B) engine, a relatively mature design as it emerged from FSD. In the last ten years the only major engine to be introduced by the Navy was the F404(F/A-18), which, in keeping with contemporary engine development practice, was fielded as a relatively mature engine. A large CIP program was not required, and the introduction of the F404 in the early 1980s is evidenced by only a small upward movement in Navy CIP funding.

The introduction of new designs exerts upward pressure on CIP funding requirements, while the maturing of engine models in the existing inventory relieves funding pressure (it should be noted that the large reduction in both USAF and Navy funding in 1986 cannot be explained by inventory effects and is more likely a result of general downward pressure on and increased competition within the RDT&E budget);

historically as an engine model ages its CIP costs decrease. This can be seen by looking at CIP funding across time for individual engines.

Figure III-2 presents cumulative funding normalized as multiples of engine FSD cost (these multiples are based on constant 1985 dollar costs) with time measured as years since MQT. By using this normalized measure, more valid comparisons can be made across a wide variety of engines. Both Air Force and Navy funding is included where engines are used by both services. In this figure are the major CIP efforts of the past 20 years. Included are examples of various mission types: fighter (J79, TF30, F100, F404), attack (TF41, TF34), transport (TF33, TF39) and bomber (TF33, F101). Note that over a twenty-year period an engine's CIP costs can exceed (in some cases by several times) the cost of its original development program.

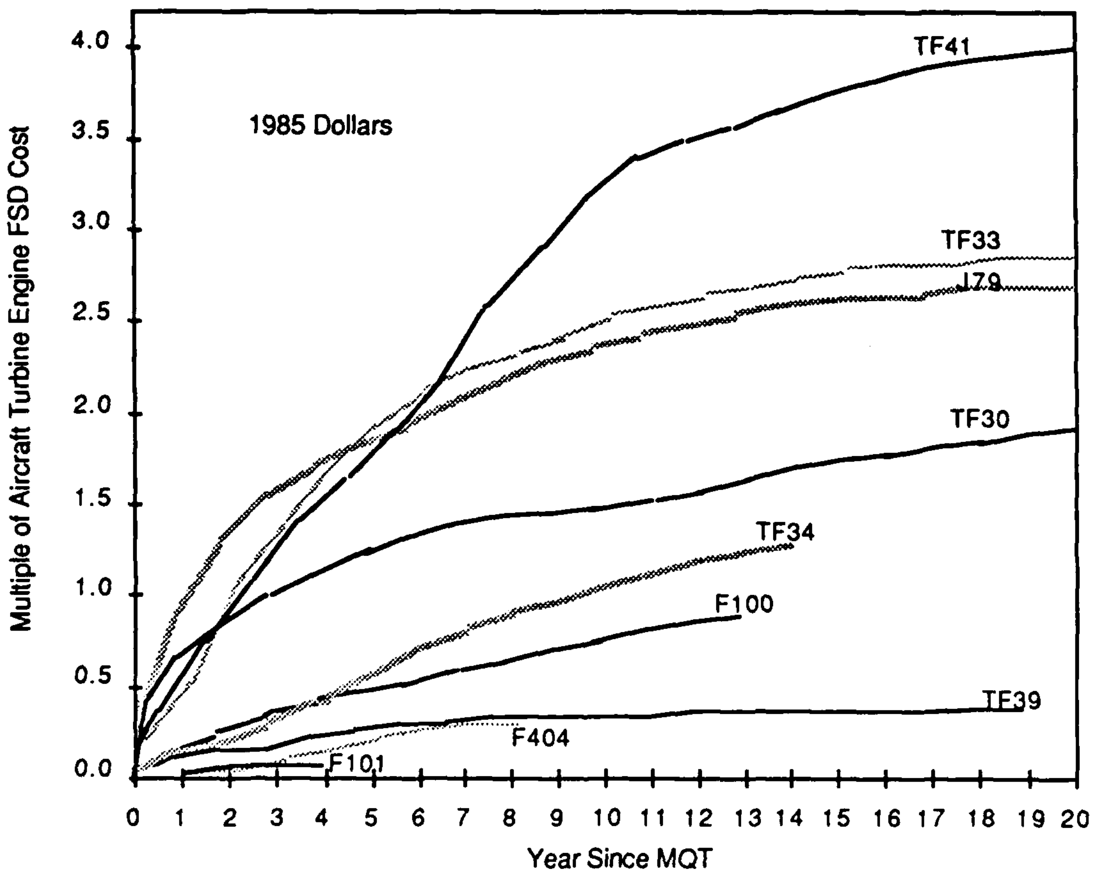


Figure III-2. Cumulative CIP Funding as a Multiple of Full Scale Development Cost

Another phenomenon which is seen in Figure III-2 is the increase in CIP funding which occurs when an engine is used for a new and different application; this is noticeable in the TF34 example. The TF34 was first developed for the Navy's S-3 antisubmarine warfare aircraft and was later used in the Air Force's A-10 attack aircraft. An increase in TF34 funding can be seen after this new application is fielded. The A-10's attack mission is different enough that problems occurred that had not been experienced in the less-demanding ASW mission. New engine operating conditions which reveal new problems call for increased CIP funding to institute corrective measures. A new application is the most extreme example of this; more subtle and more common are changes in engine operating conditions (for a given application) resulting from the implementation of new tactics (often threat-driven) or to changes in the flight envelope.

The anomalously high CIP multiples for the TF33 and TF41 are a result of unusually low FSD costs and are not indicative of inordinately high CIP costs. The TF33 and TF41 were major modifications of existing engines and thus required less effort to develop through MQT.

How have CIP costs changed over the past decades for specific types of aircraft applications? Figure III-3 displays the first ten years of CIP funding for four eras of fighter engine developments. This figure is dimensioned in the same manner as Figure III-2. Although these are all fighter engines, a normalized measure of CIP funding is still needed because they still differ widely in thrust class (16,000 lbs to 24,000 lbs), mach number (2.0 to 2.5), relative technological advance and other factors; these differences are reflected in engine FSD cost, which is our normalization factor. There is a significant decrease in relative CIP effort over engine development eras from the J79 (late 1950s) through the TF30 (mid-1960s), F100 (mid-1970s) and F404 (early 1980s); although new development process initiatives were incorporated into F404 development, the F404 is technologically of the same generation as the F100. This downward trend can be explained by the change in engine design and development practices over the years and the restriction of CIP funds to performing certain tasks (no thrust growth or new applications). The FSD process has been restructured with the objective of fielding maturer engines so that early problems are of more limited scope and severity when compared with earlier experience. Full scale development does not find and solve all military engine problems.

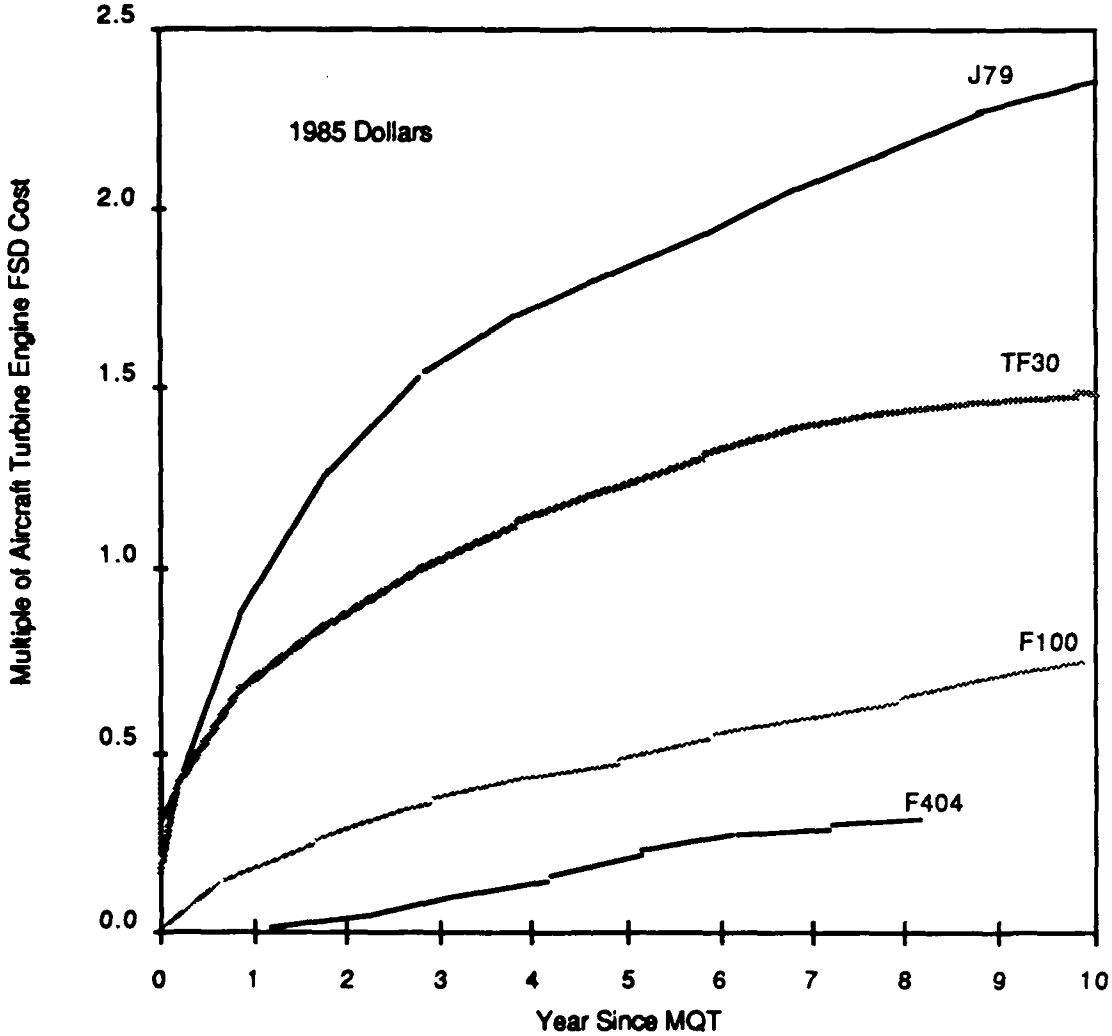


Figure III-3. Cumulative CIP Funding as a Multiple of Full Scale Development Cost: Four Tactical Fighter Engines

Commercial engines are no different in requiring engineering support for improvements after they enter service. Figure III-4 compares post-certification engineering (PCE) for the JT9D, which powers the Boeing 747, with CIP for two military transports, the TF33 and the TF39. The format is similar to our earlier displays; the qualification milestone relevant for the JT9D is the FAA certification. Because the JT9D example reflects privately-held cost information, it is not clear how much of the PCE money went to thrust growth (the original JT9D-3 was grown from 43,500 to 50,000 pounds for later JT9D-7 models) and how much of the money was spent in what the military now regard as CIP activities (safety of flight; correction of deficiencies; improvements in reliability, maintainability, repairability, and producibility; logistics support planning; and lower life cycle costs).

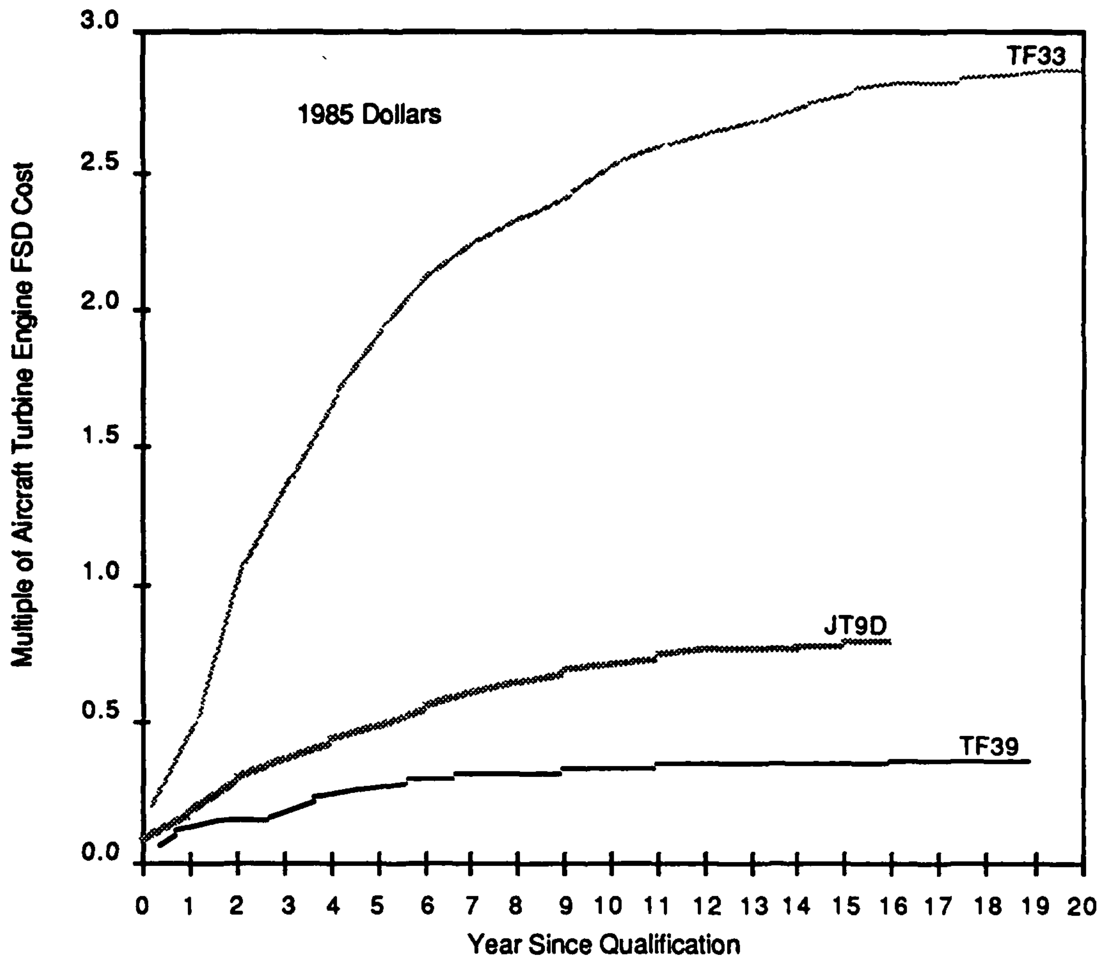


Figure III-4. Cumulative CIP/PCE Funding as a Multiple of Development Cost: A Commercial Example and Two Military Transports

B. THE BENEFITS OF CIP

There are many benefits that the military ascribe to CIP. These generally correlate with CIP objectives and are in many cases quantifiable and measurable. Of course it is impossible to know what the behavior of these measurable attributes would have been in the absence of CIP; it can, however, be said that whatever improvements are observed over the operational life of the engine, most are a result of the CIP program. The three most important benefits contributing to decreases in system life cycle costs are decreases in aircraft attrition, spares requirements and depot visit rates. Addressed below are 1) engine-related Class A accident rate, which describes engine-caused aircraft attrition, 2) unscheduled engine removal (UER) rate, which is a major driver of spares requirements and 3) and average time between overhaul (ATBO), which characterizes depot visit intervals.

Correcting safety of flight problems, particularly for a single-engine fighter aircraft, results in fewer aircraft lost in Class A accidents. Figure III-5 portrays the trend in engine-related Class A mishaps for the F-15 twin-engine and F-16 single-engine fighters.

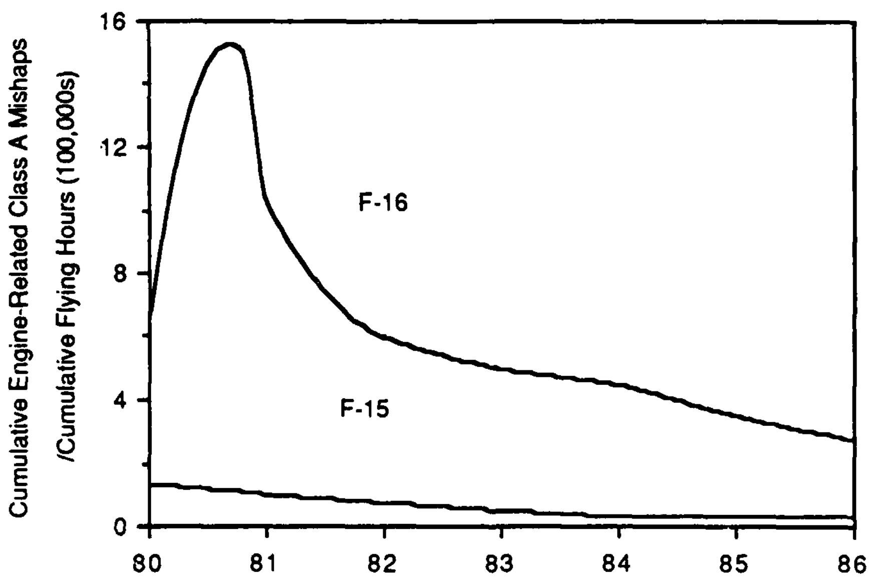


Figure III-5. F-16/F-15 Engine-Related Class A Mishaps

These data demonstrate that CIP-funded improvements in the F-100 engine have indeed reduced aircraft attrition caused by engine-related problems, particularly for the single-engine F-16. Every F-16 saved is an investment of 10 to 15 million dollars not needed for replacement aircraft.

Important and clear-cut reliability and maintainability measures include UER rate and ATBO. UERs represent a serious maintenance action that disrupts flying operations and requires the provisioning of spare engines in order to keep aircraft available in the field while removed engines are repaired. Figure III-6 shows UER rates for representative Navy and USAF fighter engines, while Figure III-7 shows experience for USAF transport engines.

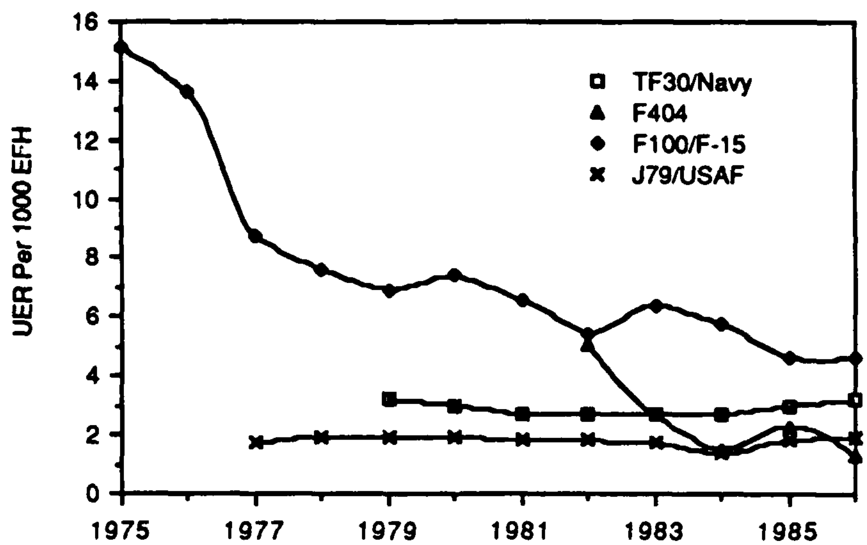


Figure III-6. Unscheduled Engine Removals: Fighter Engines

Figure III-6 portrays four generations of fighter engines at different points in their respective life cycles. The J79 and TF30 are now mature with a relatively stable UER rate. Neither is yet experiencing the gradual increase in UER rates which is often seen as a mature engine inventory ages and starts to wear out. Continuing CIP, even at modest levels, helps to delay this increase. The F100 inventory was plagued by very high UER rates in the early years of fleet operation in the F-15; with an intense CIP effort UER rates for the F100 have decreased significantly. The F404 reflects more recent development practices and is shown to be relatively more mature at its introduction into fleet service. Despite this maturity, improvements in UER rates have been made over time, showing that CIP still has a discernible impact on engines fielded under the new development regime.

Figure III-7 shows UER histories for three engines employed in the USAF's transport fleet–the T56 (C-130; also used in the Navy P-3 and E-2), TF33 (C-141; also used in the B-52) and TF39 (C-5). When comparing Figure III-7 with Figure III-6, the most striking difference is the order of magnitude difference in UER rates. The T56 is showing an increase in UER rate; this is reflective of the aging inventory and may also be a result of decreased CIP funding experienced for that engine from the mid-1970s to the early 1980s. The mature TF33 shows stability in its UER, while the newer TF39 is still experiencing improvements even after a decade of experience.

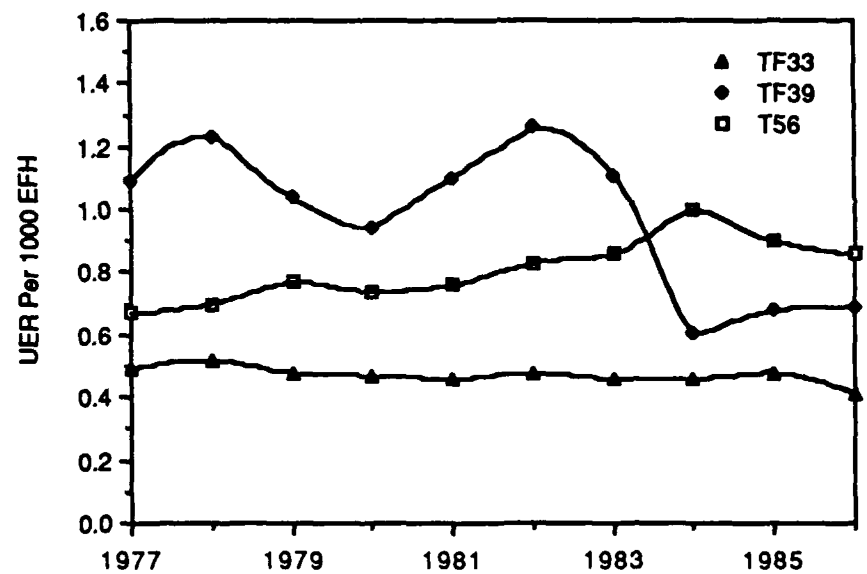


Figure III-7. Unscheduled Engine Removals: Transport Engines

The above figures reflect the inventory performance of the relevant engines. As new engines incorporating CIP-developed improvements are procured and included in the inventory, inventory performance improves; inventory improvements are also obtained as older engines returned to the depot are fitted with updated parts developed through CIP.

Thus another way of examining the effect of CIP is to look at the UER rates of successive procurement lots.

Figure III-8 shows the UER performance of ten procurement lots of F100 engines. The dates in the legend refer to the year in which a given lot was produced. Also portrayed is the increase in UERs which occurs as engines within a given lot accumulate flight hours; the slope of this increase appears to be diminishing over subsequent procurement lots.

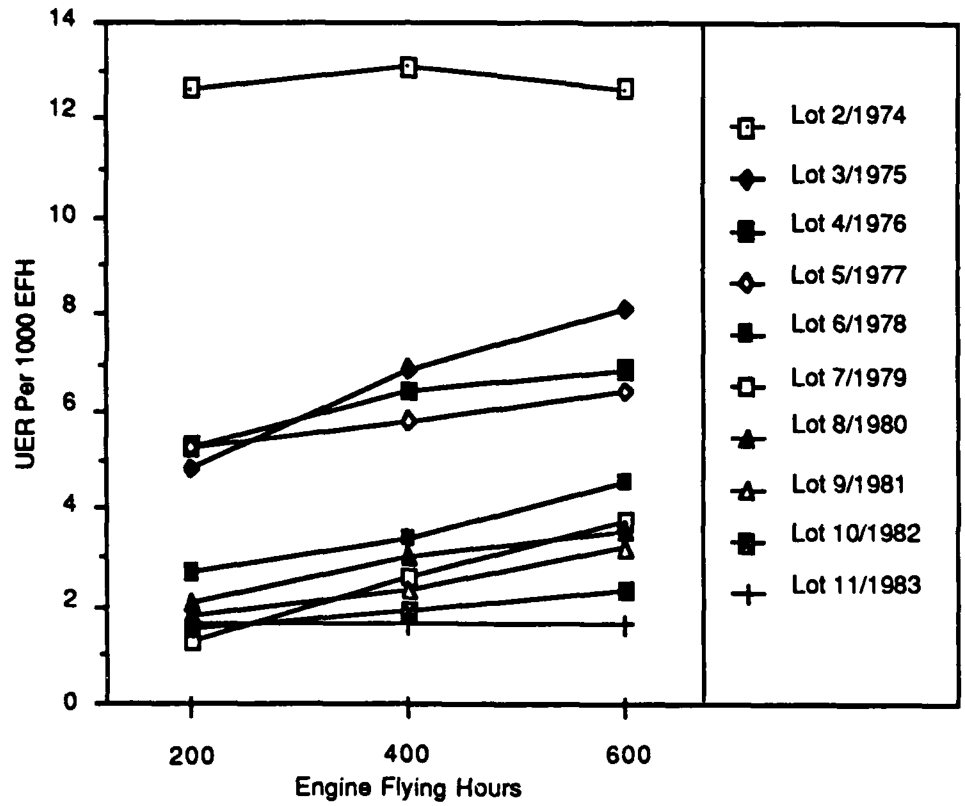


Figure III-8. Unscheduled Engine Removals: F100 Lot Experience

Another important improvement obtained through CIP is the extension of depot visit intervals or time between depot overhauls. There are two ways to look at progress in time before overhaul (TBO). Maximum time between overhaul (MTBO) refers to the flight time limit which is placed upon examples of a given engine model, after which the engine must be returned to the depot for refurbishment. Average time between overhaul (ATBO) is a measure of actual experience where all depot visits for inventory engines are relevant regardless of whether or not the MTBO was reached. Both MTBO and ATBO will improve as an engine matures; as CIP improvements are incorporated into fleet engines and ATBO increases, the MTBO for the improved engines will be revised upward. Today for engines which follow reliability-centered maintenance or on-condition maintenance, maximum times are not as relevant. Because of the empirical nature of the ATBO measure, its direct effect on depot costs and its continued relevance to modern practice, it is our preferred yardstick. Unfortunately ATBO data are not normally available from the Navy. Further, some newer engines, most notably the Air Force F100, follow a modular maintenance regime where whole engines are not the major item returned to the depot, but instead, engine modules are replaced at the base and individual modules are sent to the depot for overhaul. Because of this different way of doing things, ATBO data are not directly available for these engines. Although ATBO data by module is not normally reported for the F100, by processing raw data for individual modules returned to the depot, ATBOs can be arrived at for each module type and for the whole engines which are returned to the depot. By applying weights to these ATBOs based on the number of each module returned to the depot and their rebuild price, an equivalent-engine ATBO history can be formulated for the F100.

Figure III-9 shows the recent ATBO history for examples of USAF fighter engines including the F100 equivalent-engine measure. In Figure III-9 three levels of engine maturity are depicted. The F100 is the newest engine (it entered USAF service in 1975). It has shown substantial increases in ATBO since its introduction. In 1977 the TF30 had been operational in the USAF inventory fo. nine years and it has shown modest increases in ATBO since that time. The J79 is the most mature engine depicted (it entered the Air Force inventory in the late 1950s); recent ATBO history shows stable depot return rates. Unexpected is the higher ATBO achieved by the F100 when compared with the TF30, an engine which has been in the inventory for a considerably longer time and was subjected to a lengthy and expensive CIP program. A possible explanation is that the F100's modular design and its associated maintenance program have shifted maintenance actions from the depot to the base, which increased the depot visit interval.

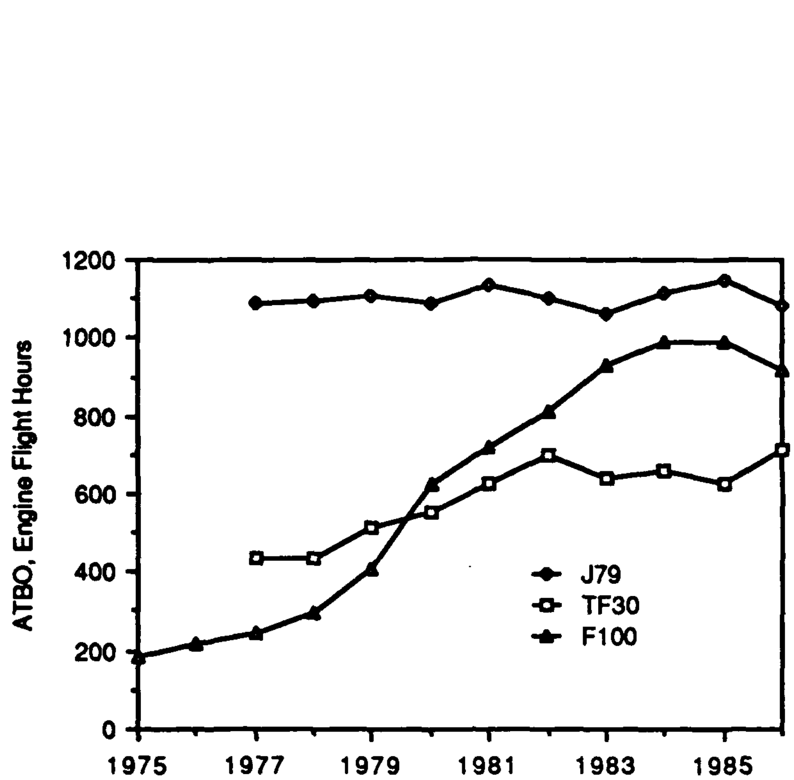


Figure III-9. Depot Visit Intervals: Fighter Engines

Figure III-10 shows the recent ATBO history for examples of USAF transport engines. The newest of the transport engines depicted is the TF39, which began USAF service in the early 1970s; the TF33 and the T56 have been in service since the early 1960s and mid-1950s, respectively. The T-56 is used in Navy installations (E-2, C-2 and P-3) as well as in its original USAF C-130 application. As can be seen, progress in ATBO is still being made for all three transport engines. The large increases in ATBO for the TF33 are unusual for an engine which has been in the inventory for such a long period. These large increases can be explained by a switch to on-condition maintenance (no MTBO enforced) in the late 1970s; on-condition maintenance has allowed the full exploitation of past TF33 CIP improvements as reflected in increased depot visit intervals. This change of maintenance regime may be the result of confidence gained through both reliability and durability improvements resulting from CIP and commercial experience (where on-condition maintenance has been traditional practice) with civilian versions of the TF33.

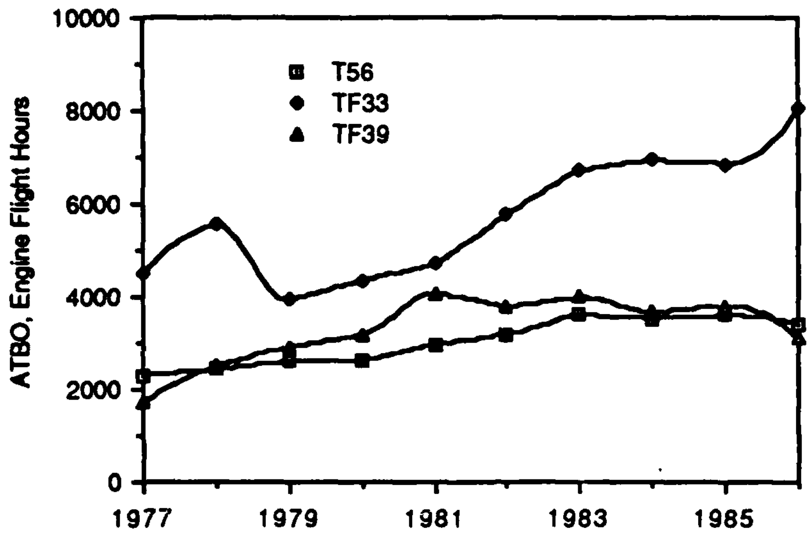


Figure III-10. Depot Visit Intervals: Transport Engines

C. CIP COST-EFFECTIVENESS

The cost-effectiveness of past CIP efforts is examined by quantifying as cost savings the benefits of CIP for past engine programs. Of particular interest are cost savings for depot repair. To arrive at depot repair savings, a life cycle cost model is employed and depot costs are generated for both the actual history of the engine in question and a hypothetical program where CIP-related engine improvements are not evident. Also of interest are savings in spares procurement and aircraft replacement due to engine-related accidents. Annual CIP costs for a given engine are subtracted from the annual flow of these cost savings to arrive at a yearly sequence of net CIP savings; these yearly net savings are in turn discounted. The emphasis is on depot cost savings resulting from increased depot visit intervals. When an engine is returned to the depot for an overhaul, it can cost 10 to 20 percent of the price of the engine each time and an engine may be returned six to twelve times in its life cycle; depot repair costs can be as much as three-fourths of the operating and support cost for an engine.[1] Also investigated for two of our example

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[1]Nelson (1980).

engines are cost savings derived from decreased spares ratios and decreased engine-related aircraft attrition.

It is useful when considering life cycle costs for engines to construct a conceptual cost profile over time. A notional pattern of cost per engine flying hour is depicted in Figure III-11. In considering the effect of engine operating costs per flying hour on engine life cycle costs, there are two measures of engine flying hours that could be applied; the engine flying hours consumed by the entire active fleet of aircraft at a particular point in time or the engine flying hours restored (EFHR) to individual engines at the shop visit.

The latter measure more accurately reflects the most current cost experience of the engine. For instance, early in the engine life cycle when the fleet is building up with new hardware, there will be many flying hours accumulated before engines begin to show up at the shop. The cost per consumed flying hour will be unrealistically low at this point in time and not give an indication of how well the engine is improving over time. The cost per consumed engine flying hour will continue to rise as indicated in the figure. The cost per flying hour restored at the shop, on the other hand, will continue to show improvement as the shop visit interval is extended, and will more nearly reflect repair experience at a particular point in time. We will use the cost per engine flying hour restored at the depot as one measure in our analysis.

An important analytical tool for the analysis of depot cost savings is a life cycle cost model presented in an earlier Rand study.[2] This model relates depot costs (in constant 1975 dollars) per engine flying hour restored to selected engine and program characteristics. These characteristics include ATBO, the selling price of the engine in constant dollars (CPUSP), the time the engine has been operational (OPSPAN), and a measure of the engine's relative technological advance (ΔTOA). The relevant equation is as follows:

$$\mathit{ln}\mathrm{DC/EFHR}=2.76182-.90604\ \mathit{ln}\mathrm{ATBO} + 1.2607\ \mathit{ln}\mathrm{CPUSP}$$
$$+.01104\ \mathrm{OPSPAN} - .02245\ \Delta\mathrm{TOA}$$

[2]Ibid.

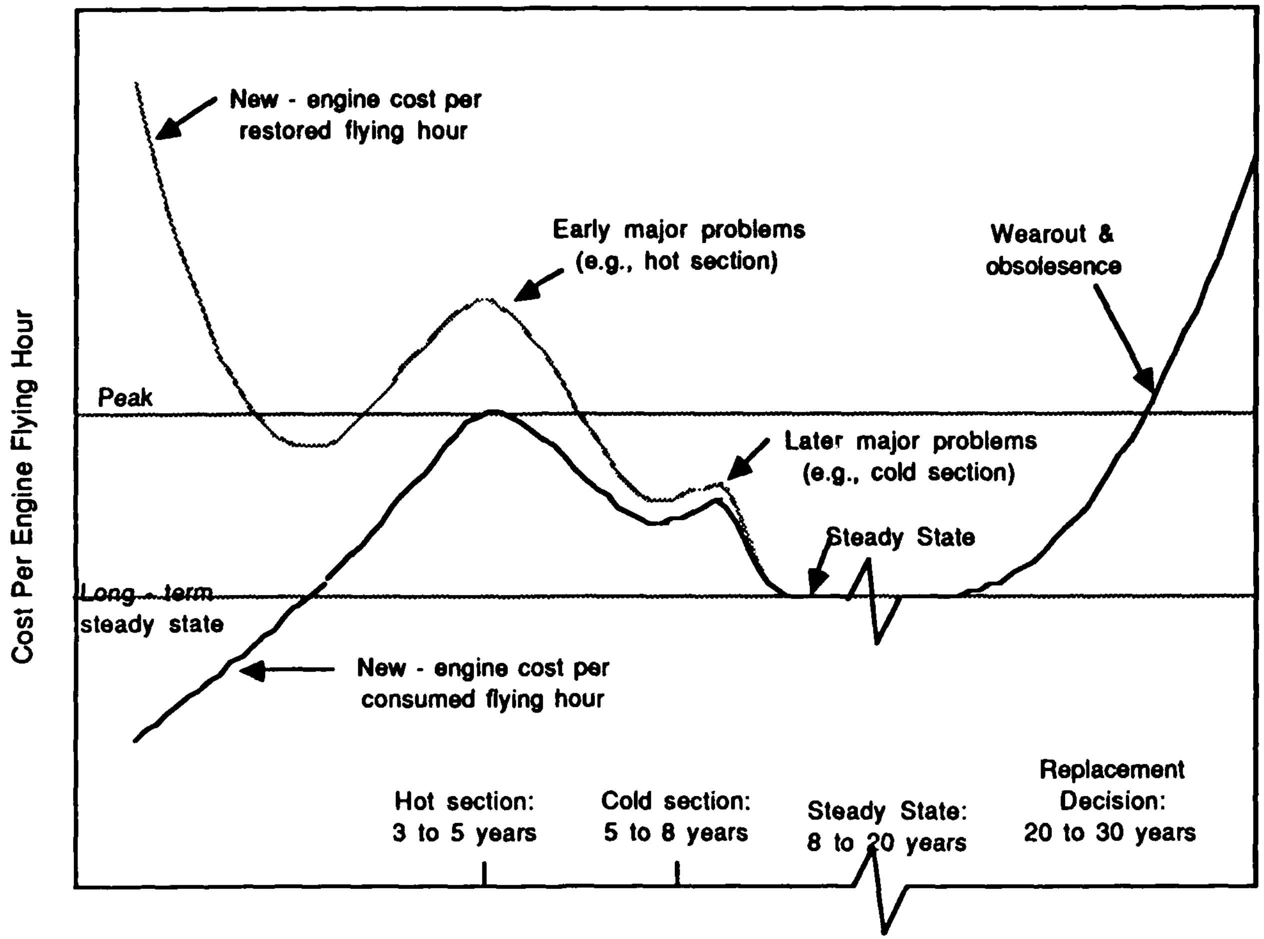

Figure III-11. Aircraft Turbine Engine Cost Per Engine Flying Hour Profile for the Engine Life Cycle

In our application of this model, engine price and ΔTOA stay constant over the life of the engine while ATBO and OPSPAN are allowed to change from year to year. As this model provides only depot costs per engine flying hour, data for an engine's flying hour program is required in order to derive total depot costs (note that by using the engine flying hour program as the equivalent of EFHR we make the simplifying assumption that the program is at a steady state). The ATBO history and engine flying hour program have been obtained from service records. Where there are gaps in ATBO histories, missing values are estimated on a trend line; where data are missing for engine flying hours, values are estimated for a fleet representative of the aircraft that those engines were applied to – for example, in the J79 analysis these include the B-58, F-104, F-4 (USN and USAF versions). When an engine has multiple applications, there is often only ATBO data available for one application.

Annual depot cost savings attributed to CIP efforts are estimated by comparing model outputs using data portraying an actual program history and a hypothesized program history where increases in ATBO are reduced (because of no CIP program) but all other program parameters are the same. Thus decreases in depot costs credited to CIP are a result of improvements in ATBO which would not have occurred without CIP. In many ways the determination of what the ATBO would be without CIP is speculative; however some guidelines are available. It would be incorrect to use the first year of ATBO experience as a maximum for a program with no CIP because as inventory engines accumulate flying hours in the first years of that engine model's fleet use, ATBO naturally increases regardless of the existence of CIP. Conversely the best no-CIP ATBO should be less than the maximum time before overhaul specified for the initial production engines. Thus the best no-CIP ATBO should fall between these two measures; in our analyses it is generally assumed to be greater than the the first year ATBO by a factor of three. Table III-1 shows the input parameters and outputs of the depot cost model for actual and hypothesized (without CIP) programs for the J79 engine; also included are CIP cost savings which are the difference in depot costs between the two scenarios. As this model was originally dimensioned in constant 1975 dollars, the appropriate escalation factors are used to express values in 1985 dollars.

Table III-1. Annual Engine Depot Costs and CIP Savings: J79 Example

Year	ATBO (flt. hours)	Unit Price (thousands 1985$)	Operational Time (quarters)	DTOA (quarters)	Depot Costs/ EFHR (1985$)	Annual Engine Flt. Hours	Depot Costs (millions 1985$)	ATBO No CIP (flt. hours)	Depot Costs/ EFHR No CIP (1985$)	Depot Costs No CIP (millions 1985$)	CIP Depot Savings: (millions 1985$)
1955											
1956											
1957											
1958	116	962	2	11.8	749.3	16750	12.6	75	1115.8	18.7	6.1
1959	175	962	6	11.8	542.6	66750	36.2	100	898.6	60.0	23.8
1960	233	962	10	11.8	437.1	100500	43.9	125	767.3	77.1	33.2
1961	291	962	14	11.8	373.3	126750	47.3	150	679.8	86.2	38.9
1962	349	962	18	11.8	330.8	177250	58.6	175	617.9	109.5	50.9
1963	407	962	22	11.8	300.7	269750	81.1	200	572.2	154.4	73.2
1964	465	962	26	11.8	278.4	352250	98.1	225	537.5	189.3	91.3
1965	523	962	30	11.8	261.6	470250	123.0	250	510.6	240.1	117.1
1966	581	962	34	11.8	248.5	693750	172.4	275	489.5	339.6	167.2
1967	639	962	38	11.8	238.2	929250	221.4	300	472.8	439.4	218.0
1968	697	962	42	11.8	230.1	1282250	295.1	300	494.2	633.7	338.6
1969	756	962	46	11.8	223.7	1630750	364.8	300	516.5	842.3	477.5
1970	814	962	50	11.8	218.6	1820250	397.9	300	539.8	982.6	584.7
1971	872	962	54	11.8	214.6	1617500	347.2	300	564.2	912.6	565.4
1972	930	962	58	11.8	211.6	1517500	321.1	300	589.7	894.8	573.7
1973	988	962	62	11.8	209.3	1417500	296.7	300	616.3	873.6	576.9
1974	948	962	66	11.8	227.1	1317500	299.2	300	644.1	848.6	549.4
1975	1104	962	70	11.8	206.7	1217500	251.7	300	673.2	819.6	567.9
1976	1162	962	74	11.8	206.3	1117500	230.5	300	703.6	786.3	555.8
1977	1085	962	78	11.8	229.4	1017500	233.4	300	735.4	748.2	514.8
1978	1092	962	82	11.8	238.4	917500	218.7	300	768.6	705.2	486.4
1979	1106	962	86	11.8	246.3	985800	242.8	300	803.3	791.9	549.1
1980	1090	962	90	11.8	260.8	913900	238.4	300	839.5	767.2	528.9
1981	1136	962	94	11.8	262.6	882700	231.8	300	877.4	774.5	542.7
1982	1100	962	98	11.8	282.6	918200	259.5	300	917.1	842.0	582.6
1983	1061	962	102	11.8	305.2	880900	268.8	300	958.5	844.3	575.5
1984	1116	962	106	11.8	304.7	888200	270.6	300	1001.7	889.7	619.1
1985	1149	962	110	11.8	310.1	863200	267.7	300	1047.0	903.7	636.0
1986	1080	962	114	11.8	342.8	794000	272.2	300	1094.2	868.8	596.6

To arrive at discounted net savings, annual CIP costs (in constant 1985 dollars, all funding sources inclusive) are subtracted from the relevant year's cost savings; this yearly flow of net savings is then discounted. The point of view is that of the decision maker at the time of the initiation of the CIP program; in the case of the J79 example the base year for discounting is 1955.

The J79 example is illustrated in Figure III-12. Here cumulative net CIP savings (cumulative savings – cumulative CIP costs) are shown undiscounted and at discount rates of 5% and 10%.

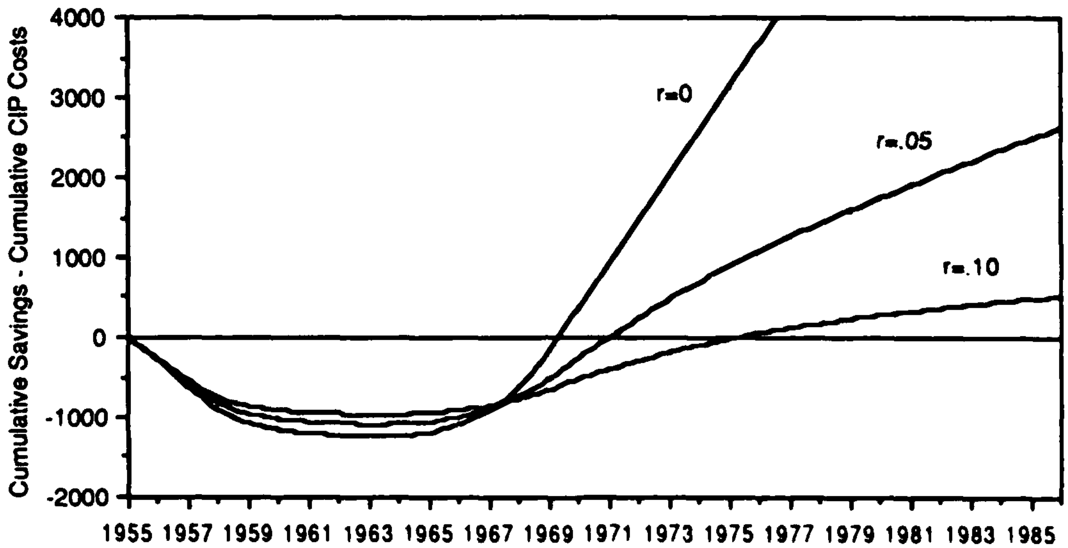

Figure III-12. J79 CIP Net Depot Cost Savings

In general CIP costs are incurred most heavily in the beginning of a program while large costs savings are not realized until a substantial fleet of engines are in the inventory; this makes the results of our cost-effectiveness analyses very sensitive to the discount rate used. This phenomenon is particularly acute in the case of the J79. Its original application, the B-58, experienced development problems and was not procured in large quantities and the F-104, another early application, was not purchased in the quantities originally planned; the J79 inventory did not grow to substantial numbers until the mid-1960s when large quantities of F-4s were procured. Further, substantial amounts of CIP money were spent *prior to* model qualification and on thrust growth in the early part of the program.

Similar analyses were performed for the TF30, F100, TF33, TF39, T56 and T700. The results of these analyses are presented in Figures III-13 through III-18.

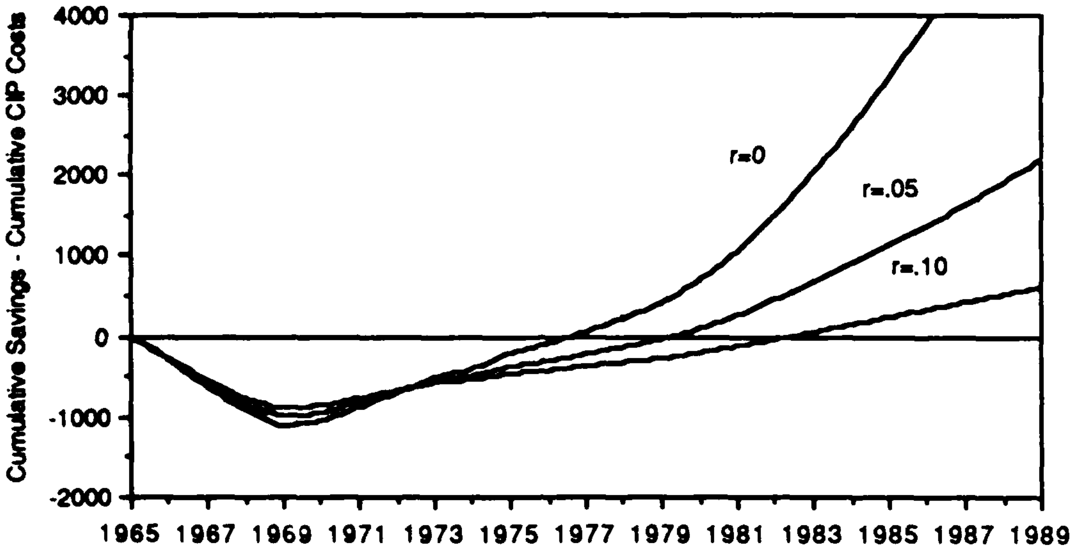

Figure III-13. TF30 CIP Net Depot Cost Savings

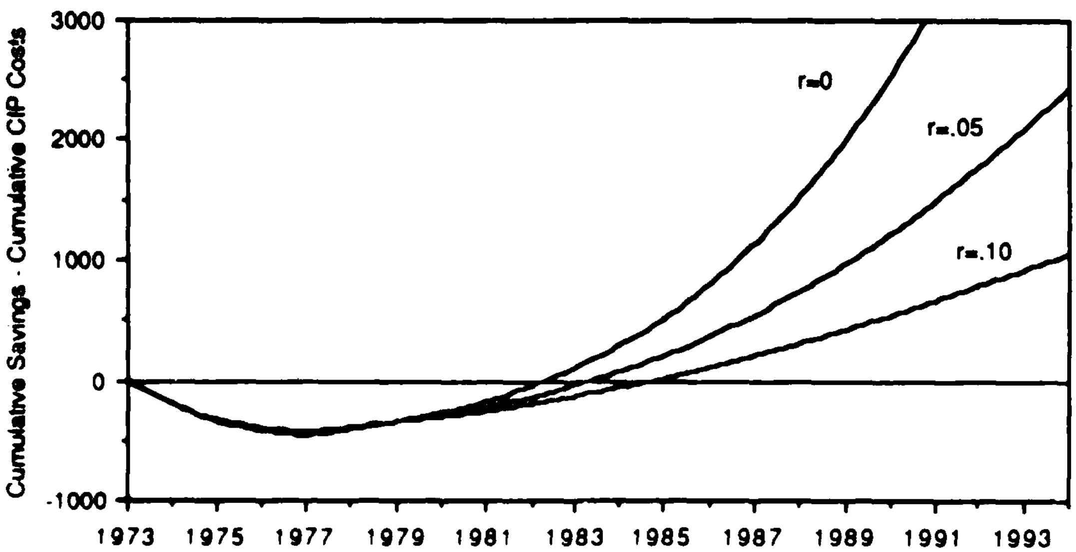

Figure III-14. F100 CIP Net Depot Cost Savings

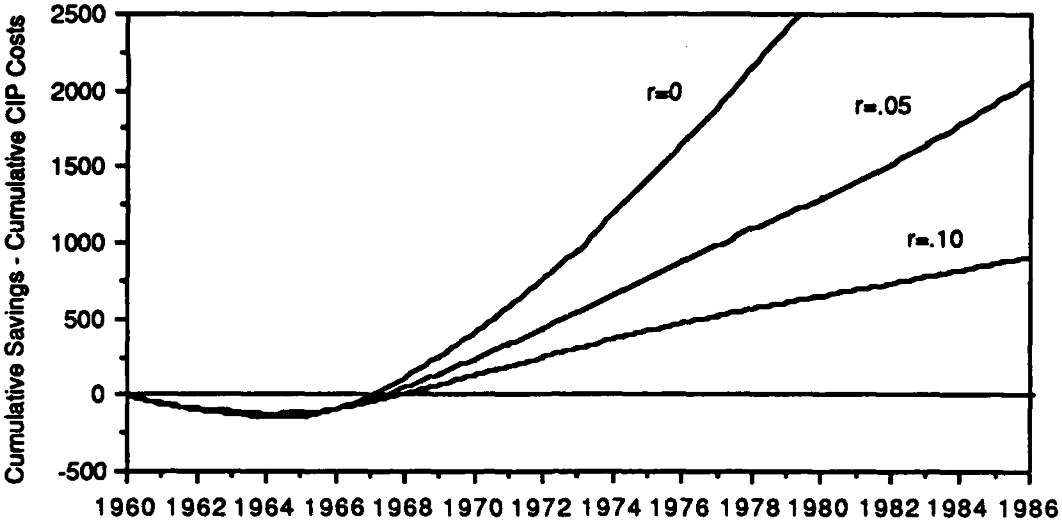

Figure III-15. TF33 CIP Net Depot Cost Savings

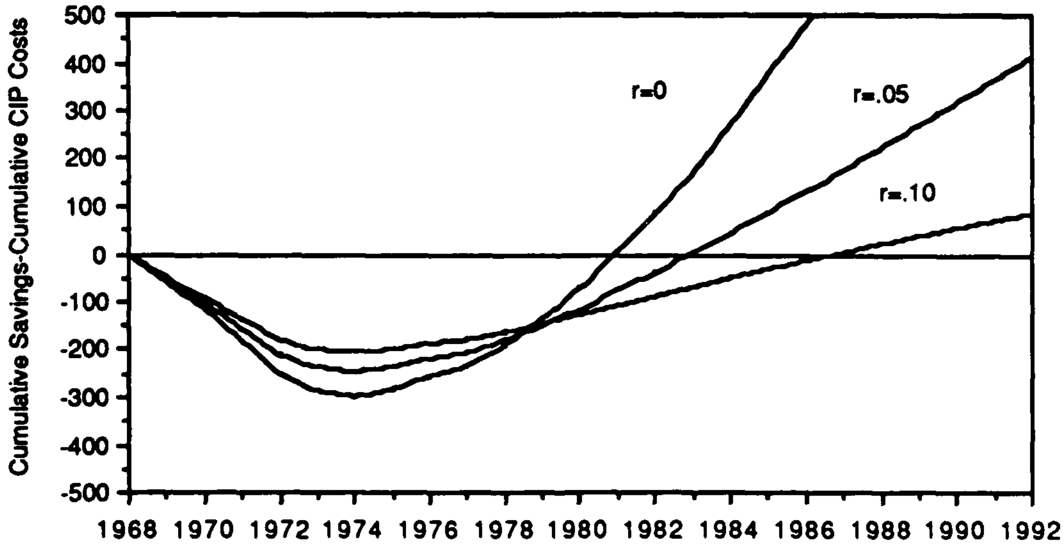

Figure III-16. TF39 CIP Net Depot Cost Savings

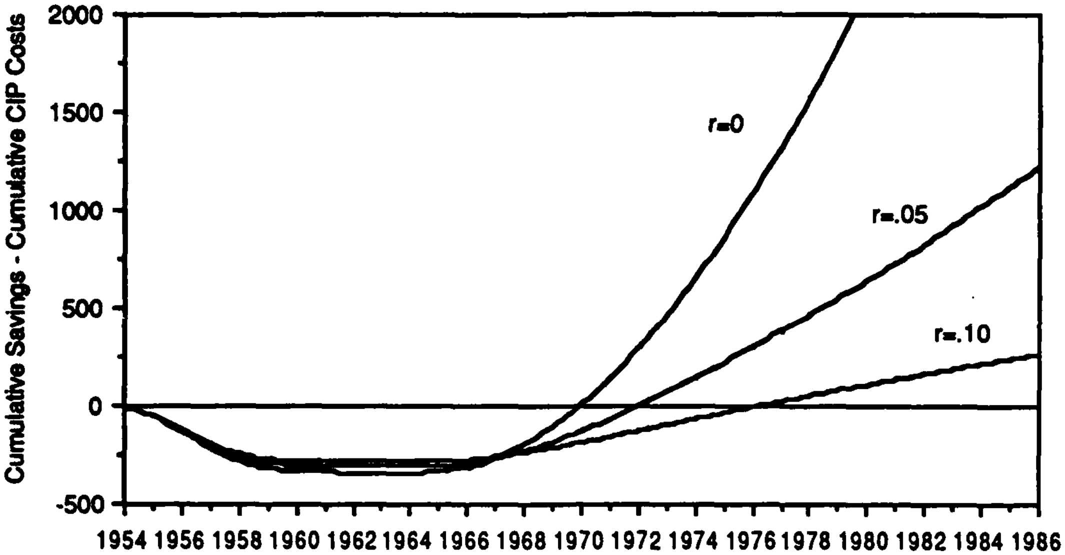

Figure III-17. T56 CIP Net Depot Cost Savings

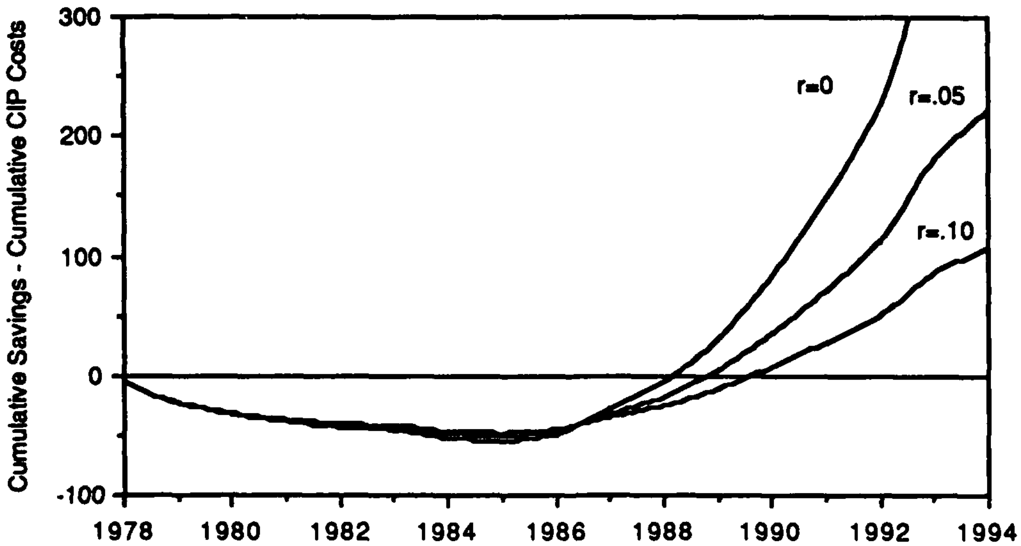

Figure III-18. T700 CIP Net Depot Cost Savings

These engines where chosen because they represent a cross-section of types (turbojet [J79], turbofan [TF30, TF33, TF39, F100] and turboshaft/prop [T56, T700]), applications (fighter [J79, TF30, F100], transport [TF33, TF39, T56], bomber [TF33] and helicopter [T700]) and development eras (1950s [J79, T56, TF33], 1960s [TF30, TF39] and 1970s [F100, T700]). Data availability was also an important criterion.

Some general observations can be made from these examples. Net cost savings range from less than 100 million dollars to more than one billion dollars and break-even points range from less than ten years to over twenty years when a ten-percent discount rate is employed. The newer programs tend to have higher net cost savings (for comparable programs), higher benefit/cost ratios and earlier break-even points than the older programs, evidently because of the aforementioned changes in the CIP process over time. Observations, notes and comments on each of the program analyses illustrated in Figures 12 through 18 are provided below.

J79. Flight hour programs are included for the F-104, B-58, and all USN and USAF versions of the F-4. ATBO data are taken from USAF experience and considered characteristic of Navy experience; depot data were not available from the Navy .

TF30. Flight hour programs are included for the F-111 and F-14; A-7 flight hours are not included. All CIP costs are included regardless of source and intended application (including A-7). CIP costs cover development of thrust growth versions of the TF30. ATBO data are taken from USAF experience and considered characteristic of Navy experience; depot data were not available from the Navy. Projected net savings beyond 1986 are based on 1986 CIP funding levels and flight hour program, and on the best ATBO achieved through 1986.

F100. Flight hour programs are included for both the F-15 and F-16. Equivalent engine ATBO history (as described earlier) for F-15 experience is used. Projected net savings beyond 1986 are based on 1986 CIP funding levels, an equivalent engine ATBO peaking at 1000 flight hours (best observed through 1986 was 980 flight hours), and a flight hour program assuming procurement levels of F-15s and F-16s as specified in the FY87 President's Budget. The 1000 flight hour ATBO is no doubt conservative since some major engine life improvements have yet to see fleet service.

TF33. Flight hour programs and ATBO history for the B-52 and KC-141 are used in the analyses. The early break-even point and relatively large net cost savings for the TF33 program are most likely a result of spinoff from parallel engineering support provided customers of the commercial version of the TF33 (JT3D) by Pratt & Whitney.

TF39. The flight hour program and ATBO history for the C-5, the only application of this engine, is used. The TF39 fleet is the smallest of our example engines with only 300 engines in the inventory. Projected net savings beyond 1986 are based on 1986 CIP funding levels and flight hour program, and a peak ATBO of 4000 hours. Not included in these projections is the flight hour program of the proposed C-5B fleet.

T56. The flight hour program for all military aircraft applications is used, CIP costs for all services are included, and the ATBO history applied is based on USAF (C-130) experience; again, Navy depot data were not available. The T56 CIP program analysis is inherently less reliable than those analyses for turbofan and turbojet engine programs because the life cycle cost model employed was not originally intended to be used for turboshaft engines. However there is no *a priori* reason that this model would overestimate net CIP savings for turboshaft/turboprop engines. As ΔTOA is not relevant to turboshaft engines, its value is set to zero in the depot cost model.

T700. The flight hour program for all military aircraft applications is used and CIP costs for all services are included. Net savings projected past 1986 are based on an estimated flight hour program provided by the manufacturer as corroborated by the services, two-thirds of the CIP funding requested, and ATBOs derived with a linear time trend peaking at 1200 hours. Because of the lack of inventory experience and uncertainty behind many of the assumptions underlying projected fleet flying hours and depot visit intervals, the analysis should be considered tenative. The T700 is the only helicopter engine included in our sample; because the T700 is a turboshaft engine, the T700's CIP analysis shares the same problems as the T56 analysis.

The life cycle cost method relied on in these analyses was developed before the introduction of newer maintenance practices, being applied to an increasing portion of the fleet.

A good case can be made for the cost-effectiveness of CIP just from depot cost reductions alone. All of the other benefits attributed to CIP including lower aircraft attrition and fewer spares purchases, even though substantial, were not included in the above analyses. In summary, CIP benefits exceed CIP costs based on depot savings alone, and the program has been of value for a wide variety of engines.

To gain a better understanding of the total value of CIP, attrition and spares savings have been estimated for two of our example programs, the J79 and F100 (no attempt has been made to quantify base level maintenance savings). Savings from lower rates of engine-caused class A accidents are calculated on the basis of the difference in rates at the beginning of the program and improved rates later in the program which are assumed to be a result of CIP efforts. This difference in rates is translated into the number of aircraft which would have been lost annually (given the same flight hour program) if no CIP was undertaken; these annual losses are in turn expressed as dollar savings based on the flyaway cost of the aircraft in question. Annual attrition cost savings are discounted in the same manner as depot cost savings.

Spares savings are determined by examining the decrease in the spares ratio (defined here as the ratio of total engines to engines installed in aircraft) over time. For fighters this ratio will exceed two during aircraft development and then decrease over time. In our analysis we attribute a major portion of this decrease to CIP improvements. Decreases in the spares ratio not related to CIP could stem from improvements in logistics and maintenance methods The difference between the actual spares ratio and a hypothetical spares ratio based on no CIP is quantified in dollar terms depending upon the yearly number of additional engines purchased for installation (i.e. aircraft procurement quantity); the cost of the additional spare engines which would have had to be bought to sustain the higher (no CIP) spares ratio is counted as a CIP cost saving. As in the case of depot and attrition savings, yearly spares savings are discounted.

Figure III-19 shows net CIP savings for the J79 including attrition and spares savings as well as depot savings; the discount rate used is ten percent. Attrition savings are for the F-104 and F-4. The engine-related Class A mishap rate for the single-engine F-104 fell from 30 to 10 aircraft per 100,000 flying hours; for the twin engine F-4 this measure fell from 2 to .5 aircraft per 100,000 flying hours. The unit value of saved F-104s and F-4s is placed at six million and twelve million dollars (constant 1985 dollars), respectively. The engine spares ratio of the F-4 fleet reached 1.33 in the mid-1970s; it is assumed that without CIP the spares ratio would have leveled at 1.75.

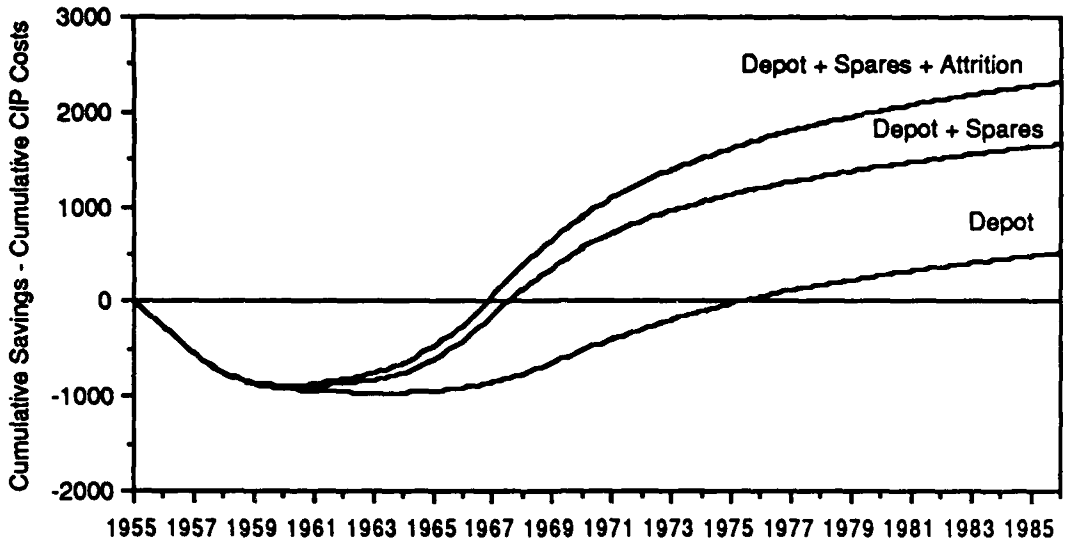

Figure III-19. J79 CIP Net Cost Savings: Depot, Attrition and Spares

Figure III-20 shows net CIP savings for the F100 including attrition and spares savings as well as depot savings; the discount rate used is ten percent. The only aircraft included in calculating attrition savings is the F-16; attrition for the twin-engine F-15 has been negligible. The F-16's engine-related Class A mishap rate has fallen from 6 to 2.5 aircraft per 100,000 flying hours; although there was a peak rate of over 15 aircraft per 100,000 flying hours early in the program, 6 aircraft per 100,000 flying hours is considered the no-CIP baseline. The unit value of saved F-16s is placed at 14 million dollars (constant 1985 dollars). The engine spares ratio of the F-15 and F-16 fleet reached 1.5 and 1.4, respectively, in 1986; it is assumed that without CIP the spares ratio would have leveled at 1.75. Not included in this analysis are spare engine modules.

As can be seen, the addition of estimated attrition and spares savings increases substantially the net cost savings attributable to CIP investment for both the J79 and F100.

Table III-2 summarizes the above analyses. Values are provided for model inputs and outputs including ATBOs, break-even points, net savings and benefit/cost ratios.

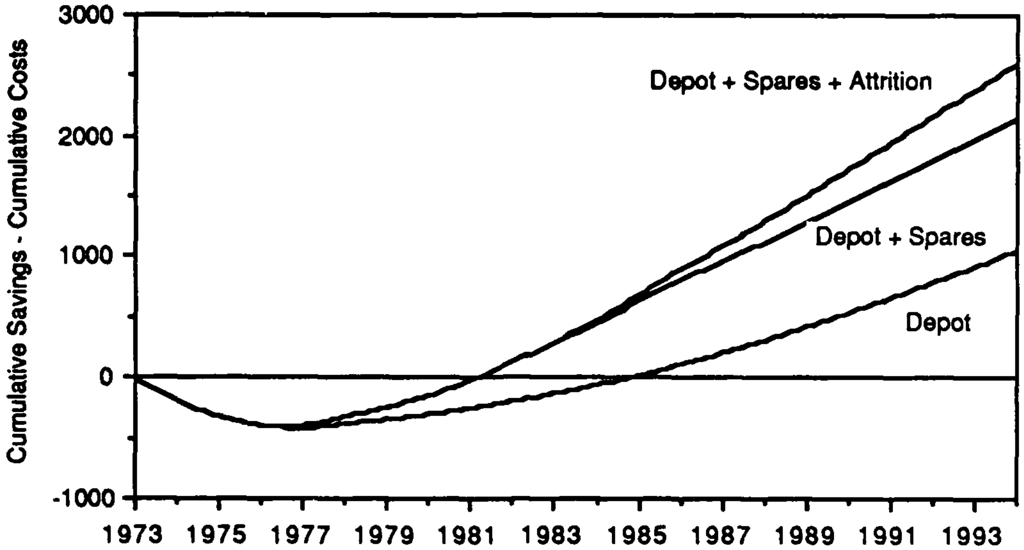

Figure III-20. F100 CIP Net Cost Savings: Depot, Attrition and Spares.

It should be noted that the above analyses treat the costs and benefits of individual component improvement programs in their entirety and do not deal with the marginal value of yearly CIP expenditures. In these analyses incremental improvements in life cycle costs can not and should not be related to incremental CIP expenditures; incremental improvements may be the result of CIP tasks undertaken many years before and represent the results of cumulative effort. An analytical tool which could deal with the marginal value of CIP expenditures would be very useful in determining the proper level of annual CIP funding and the allocation of that funding between engine programs and tasks.

Table III-2. Summary of Cost-Effectiveness Analyses

	Best ATBO Achieved (flt. hours)	Best ATBO No CIP (flt. hours)	Break-even Point (years from CIP start)	Net CIP Savings Discounted @ 10% (millions of 1985 dollars)		Benefit/Cost Ratio 10% Discount Rate (millions of 1985 dollars)	
				20 Years	30 Years	20 Years	30 Years
Depot Savings Only							
J79	1149	300	20	60	515	1.0	1.4
TF30	713	250	18	337		1.3	
F100	1000	500	12	1066		2.2	
TF33	8055	1200	8	649		3.3	
TF39	4080	1000	19	22		1.1	
T56	3600	1000	21	-31	243	0.9	1.5
T700	1200	600	12	107		2.1	
Attrition and Spares Savings Included							
J79	1149	300	12	1623	2276	2.3	2.9
F100	1000	500	8	2610		3.9	

Cost-benefit analyses performed by the services to help determine the allocation of annual funding to CIP tasks seem overly optimistic in the magnitude of benefits assumed; their ground rules concerning discounting and inflation are not clear. Figure III-21 shows the results of USAF-presented analyses for CIP tasks funded in 1985, 1986 and 1987. Benefit/cost ratios are estimated to be as high as 70 with much variation between engines.

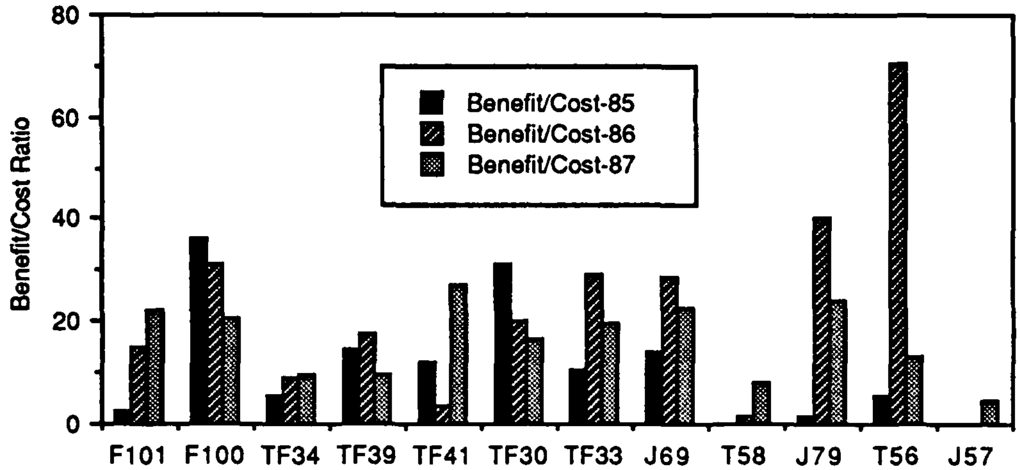

Figure III-21. USAF-Presented Benefit Cost Ratios for CIP Tasks Funded in 1985, 1986 and 1987

D. SUMMARY

This section examined the costs, benefits, and cost-effectiveness of past CIP efforts. CIP costs have decreased over time at both the level of the individual engine programs and the services' total CIP funding commitments. Major sources of this decrease include changes in the engine design and development process and what CIP funds can be used to accomplish. Despite improvements in the development process, engine CIP is still necessary and provides quantifiable benefits for engines developed under the new regime. When examining the costs and benefits of CIP at a high level of aggregation using conservative ground rules there can be little doubt about the value of past and ongoing programs. This record of success should be considered when major changes in CIP policy are examined. Policy changes in the past are working. For modern engines there are lower CIP expenditures relative to FSD expenditures than for earlier engines; in our analysis of net life cycle cost savings, benefit/cost ratios are generally higher and break-even points are achieved earlier for more recent engine component improvement programs. In the future it would be advantageous to develop analytical tools capable of assessing the marginal value of CIP expenditures.

IV. POLICY OPTIONS FOR CIP

This section addresses policy options for CIP, to include:

- Transitioning financial support of CIP to the private sector
- Competing some or all CIP funding
- Considering other approaches to accomplishing CIP activities.

It examines circumstances which might make private sector support of CIP feasible and discusses how the government can decide when to rely on private sector support. It looks at the nature of CIP tasks and discusses which types of tasks are amenable to competition. It also discusses how competition in engine acquisition has enhanced opportunities for competing CIP and considers how competing CIP might affect government objectives. Finally, it examines the ways in which product improvement and engineering support are carried out for other components of major systems and assesses the implications of adopting these methods for government objectives.

By "privatization" we mean the gradual transitioning of financial support for all CIP activity to the private sector, perhaps on a program-by-program basis. This implies total loss of government control, phasing out the CIP program elements, and loss of visibility of any funds spent to achieve CIP objectives. A mix of private and government control could be possible under partial privatization (cost sharing). By "CIP competition" we mean competition for CIP funding among different contractors.

A. CURRENT STATUS

This section discusses the current status of the CIP program in the context of the privatization issue. While there have been changes in CIP policy over the past several decades, the policy changes discussed in this report involve fundamental change.

The free world market for military and commercial engine applications is now approaching $15 billion, with the overseas market accounting for about one-half. General Electric and Pratt & Whitney each have about one-third of the world market share, so aircraft turbine engines have a positive impact on our trade balance. Rolls Royce is the principal foreign competitor with about one-sixth of the total market. General Electric and Pratt & Whitney must continually press technology to stay ahead of foreign competition.

The U.S. military is continually demanding improved technologies to obtain the best aircraft systems for military applications. Two firms, GE and Pratt & Whitney (a division of United Technologies), have over 80 percent of the military market for large-scale engines. Other companies – Allison, Avco Lycoming, Garrett, Teledyne, and Williams in the U.S, Rolls-Royce in England and SNECMA in France – have smaller portions of the military market.

Total CIP funding in fiscal year 1987 was approximately $150 million, of which the two largest engine companies, GE and Pratt & Whitney, received over 80 percent. These two largest companies also received about 80 percent of the approximately $5 billion (in 1985 dollars) in Air Force and Navy CIP funds for the 1970-1986 period. Allison received almost 10 percent of the total CIP funds, and others, including Garrett, Rolls Royce, and Teledyne received the remaining 10 percent. (If Army CIP funding had been included in this analysis, we would still see GE and Pratt & Whitney receiving the largest shares, but other shares might be slightly different, and Avco-Lycoming would also be included.)

Table IV-1 illustrates the current status of some CIP programs by representative mission area. In the support mission area, there is no CIP program, since commercial engines are bought off-the-shelf and are maintained by contractors through competitive procurement. This is an acceptable solution for small fleets that do not have a strategic mission. In the tanker, airlift, and helicopter missions, there have been several instances in which the military has adapted commercial engines to military use or there has been a concurrent commercial project.

In some of these cases, the military has relied on commercial support for product improvement, and in other cases there have been both CIP and private sector improvement programs. Thus, there has already been some private sector support of military engines. For example, the KC-135R tanker engine (the F108) was purchased under commercial ground rules. The government has, however, established a $45 million fund for CIP type activities for problems unique to the military, but there are no specific CIP contracts. The selling price of each of the first 1,100 engines have a $41,000 add-on to establish the fund. The C-17 transport engine (the F117) is being purchased completely under commercial

Table IV-1. Examples of Current CIP Status by Representative Mission Areas

Mission Area	Example Engines	(Aircraft)	Current Status
Strategic			
• Bomber	J57 TF33 F101	(B-52) (B-52) (B-1B)	Generally government-funded CIP. Military usually sole customer. Exception has been the subsonic B-52 where J57 and TF33 had commercial counterparts and so benefited from some private investment as well as providing a contribution to commercial engine improvements
• Tanker	J57 TF33 CF6 F108 [CFM56]*	(KC-135) (KC-135) (KC-10) (KC-135R)	Sustaining engineering and product improvement have been placed under the engine company in specific examples where the commercial market leads.
Tactical			
• Fighter/Attack	J79 J52 TF30 TF41 TF34 F100/F110 F404	(F-4) (A-6) (F-111, F-14, A-7) (A-7) (A-10) (F-15, F-16) (F/A-18, A-6)	Totally military support, no commercial customers
• Helicopters	T53 T55 T63 T700	(UH-1 AH-1) (CH-47) (OH-6, OH-58) (UH-60, AH-64)	Some commercial counterparts primarily derived from military programs. Army discontinued CIP for some older engines for a period of time. Recently there have been problems with these engines, and the Army has begun to suffer degraded fleet capability and is trying to restore CIP.
Airlift	T56 TF33 TF39 F117 [PW2040]*	(C-130) (C-141) (C-5A&B) (C-17)	Sustaining engineering and product improvement have been placed under the engine company in specific examples where the commercial market leads.
Support	JT8D J60	(C-9) (T-39)	Commercial engine off-the-shelf – sustaining engineering and product improvement under engine comany.

* Models in brackets are commercial counterparts.

ground rules; the government will pay the same price as commercial customers and is relying completely on the company to fund product support.

In the helicopter mission area, the Army has discontinued CIP funding for some older engines. Recently the Army has begun to suffer significant problems with these engines in the field, and it is restoring CIP to these engines. Specific examples include the T53 and T63 engine programs.

In the fighter/attack mission, CIP is purely government-funded, since these engines have no commercial counterparts. In the bomber mission, CIP is also almost purely government-funded. (An exception is the B-52H engine, the TF33, which has a commercial counterpart in the JT3D. There has been a mix of government and private funding to obtain improvements for that engine.)

B. PRIVATIZATION OF CIP

There are several ways of funding engine improvements. These include:

- *Paying for CIP in the price of the engine.* This is traditional commercial practice, but not currently normal government practice. The government followed this course in the 1940s, prior to establishing CIP in the 1950s. (See the CIP history in Section II.) Commercial customers pay a price which includes the engine, CIP, warranty coverage and amortization of the development cost. In traditional government practice the government pays for development, and engines are purchased on a cost-plus-fixed-fee or cost-plus-incentive-fee basis early in operational use and on a fixed-price basis later. But government fixed price is based on cost plus allowable fee (costs are audited), not at all similar to commercial fixed price which does not require disclosure of costs. Government contracts typically include independent research and development and EAPS, but not CIP. Paying for CIP in the price of the engine, commercial style, is privatizing CIP.
- *Paying for CIP in a lump sum.* In the past, CIP was funded as a production add-on. A variation on this occurred recently with the acquisition of the F108 engine. The government paid a discounted price for the engine (less than commercial customers) and established a $46 million fund to provide CIP support.
- *Government creation of incentives for contractors to reduce the need for CIP.* Such mechanisms could include warranties, incentive contracts, or contractor maintenance which make contractors responsibie for the actual performance of the engine over a period of time. This option would require considerable restructuring of the acquisition process.

- *Paying for CIP in separate annual contracts.* This is the current system, which allows for task definition and direction and control of activities by the military service, control of annual funding for each engine program by the service, and visibility of CIP funds by Congress.

Which options are available and effective for the government in a given case varies with the acquisition method for each engine. The existence of a commercial market for the engine and competition in the engine acquisition influence how CIP can be funded. In addition, whether an engine is in production or out of production influences how much leverage the government has. These issues are discussed below.

Table IV-2 lists some of the implications of phasing out government funding for CIP. Privatization of CIP involves major changes in the direction and control of CIP–a movement from the current system of military control of priorities toward company control. There are also issues of configuration control. Currently, the government must approve all changes to the engine configuration. Under privatized CIP, this might have to be renegotiated–companies would not be willing to invest in product improvement without some indication that the government would accept changes to the engine. Under the current system, the government has enough leverage to ensure that its programs are carried out, while under privatization, the government would have less leverage. In addition, data rights would have to be renegotiated–under the present system, on company-funded work, the company retains data rights. If this could not be done, it could hamper future plans for engine or spare parts competitions.

1. Privatization by Mission Area

The possibilities for privatization of CIP vary considerably by mission area, mainly because of the existence or lack thereof of commercial counterparts for military engines. Table IV-3 shows selected examples of possibilities for transitioning CIP to the private sector by mission area.

Table IV-2. Implications of CIP Privatization

Government Considerations	Military Fund CIP	Private Sector Fund CIP
Funding Source(s)	Direct CIP contract Indirect (PES/EAPS) FMS Contractor (commercial derivative) Other (fuel, military qualifying test, etc.)	Company recovery of cost elsewhere (selling price, overhead, warranty, IR&D, spare parts) FMS might continue Contractor voluntary Indirect (PES, EAPS)
Direction	Military direction, military priorities	Company direction, company priorities based on incentives provided by government
Control	Military configuration control - determine changes and when introduced - military data rights	Company configuration control - company data rights could hamper parts breakout programs
Leverage	Military decides funding level for individual program, monitors progress	Company decides - based on incentives provided by government
Responsiveness	Very rapid	Depends on problem and potential in relation to company priorities and incentives provided by government
Visibility	High	Visible only in performance and reliability of engine
Business Strategy	Allowable cost plus fixed fee for CIP or fixed price incentive	Companies may try to cover CIP costs in other ways, especially in non-competitive procurements. With commercial engines, governement pays commercial price.
Market Strategy	Company does CIP because costs are covered	Company may have incentives to do CIP if there are commercial customers, competitive production, warranties, or other contract incentives. Otherwise, incentive is to sell spare parts and the next engine, not make the current one more reliable.
Other Benefits	Keep design team and corporate memory Technology insertion opportunities	No military organization required for planning, funding allocation, monitoring, cost savings from CIP line item
Data Rights	Owned by government	Owned by company on company - funded work unless renegotiated or changed by legislation.
Risk/Uncertainty	Military can plan long-range program as long as budget is not seriously cut	No CIP likely for engines that are out of production unless there are contract incentives. Possible loss of design team (corporate memory), and long-range planning integration.
Length of Design Life	25-40 years	May decrease due to lack of improvements and high support costs - military would seek funding for next program in hopes of reducing LCC

Notes to Table IV-2

[Definition of terms under "Government Considerations"]

Direction	The ability to set goals for long-term improvement and to integrate individual CIP tasks into a long-range plan for product improvement.
Control	The ability to set priorities and, to some extent, the methods for accomplishing individual CIP tasks.
Leverage	The ability to induce a contractor to perform in accordance with government objectives.
Visibility	The ability to separate expenditures for budget elements for CIP from others in the Federal budget, in the RDT&E budget, and in an acquisition program.
Responsiveness	The degree to which contractors comply with government directives and the speed with which resources can be reallocated.
Accountability	Being responsible for products and the use of funds, in this case, the services being responsible to Congress for CIP funds and CIP contractors being responsible to the government for the funding and products of CIP contracts.
Business strategy	Contractor planning and determination about which products and services to produce and how to invest its profits and retained earnings.
Market strategy	Contractor planning an approach to pricing of products and services for market sectors.
Data rights	The legal right to use designs and engineering data to produce products.
Risk	For the military, the chance that the CIP tasks performed will not be those the military would have chosen or will not turn out to meet standards. For contractors, chance of loss or reduced profits.
Uncertainty	The inability to predict short-term outcomes, the variability in planning several years ahead.

Table IV-3. Example Possibilities for CIP Privatization by Mission Area

Mission Area	Example Engines (Aircraft)	Possibilities for CIP Privatization
Strategic		
• Bomber	J57 (B-52)	
	TF33 (B-52)	
	F101 (B-1B)	
•	NEW PROGRAMS	None likely to arise in future unless there are commercial counterparts or incentive contracting.
• Tanker	J57 (KC-135)	KC-10 purchased under commercial ground rules - USAF is a small customer among many KC-135R - purchased under commercial ground rules - fund established for USAF engine usage problems.
	TF33 (KC-135)	
	CF6 (KC-10)	
	F108 (KC-135R)	
	[CFM56]*	
	NEW PROGRAMS	Considerable potential for privatization.
Tactical		
• Fighter/Attack	J79 (F-4)	
	J52 (A-6)	
	TF30 (F-111, F-14, A-7)	
	TF41 (A-7)	
	TF34 (A-10)	
	F100/F110 (F-15, F-16)	
	F404 (F/A-18, A-6)	
	NEW PROGRAMS	None likely because no commercial counterparts However, where there is procurement competition, government might have leverage to ask for cost sharing. Government needs to maintain configuration control.
• Helicopters	T53 (UH-1 AH-1)	T63 was privatized in that the Army did not fund CIP and company did proceed with improved commercial derivatives. T700 has CIP and also commercial derivatives; each has provided benefits to the other.
	T55 (CH-47)	
	T63 (OH-6, OH-58)	
	T700 (UH-60, AH-64)	
	NEW PROGRAMS	Some possibility for privatization
Airlift	T56 (C-130)	C-17 engine is privatized.
	TF33 (C-141)	
	TF39 (C-5A&B)	
	F117 (C-17)	
	[PW2040]*	
	NEW PROGRAMS	Privatization is expected to continue as opportunities arise.
Support	JT8D (C-9)	Off-the-shelf engines purchased under commercial ground rules and maintained under competitive contract.
	J60 (T-39)	
	NEW PROGRAMS	Considerable possibility for privatization

* Models in brackets are commercial counterparts.

The engines for tankers, transports, and support aircraft often have commercial counterparts. In some cases, a commercial engine was adapted for military use (the F108 in the KC-135R tanker), while in others a commercial engine was derived from a military one (the CF6 from TF39 in the C-5A/C-5B transport). The CF6 engine in the KC-10 tanker is the same engine that is used in commercial aircraft.

Increasingly, the government has moved toward acquiring engines with commercial counterparts under commercial ground rules, that is, at a commercial price (not cost-plus). In such cases, the government will be purchasing product improvement in the same way that commercial customers do. In making this decision, there are several important factors for the government to consider, including:

- *Fleet size*. When the government is buying relatively few engines (in the hundreds rather than the thousands), commercial ground rules, including privatized CIP, make more sense. A substantial CIP effort to improve the operation of relatively few engines would not be necessary, particularly if the engine company is improving the engine to win new customers in the commercial market.
- *Usage patterns*. When the government usage patterns are very similar to the commercial, the government can derive benefit from the same improvement efforts that benefit the commercial engine. Military transport engines do develop different problems from commercial airline engines because they fly fewer hours but do more training. When the military usage is unique, separate CIP funding is required.
- *Life cycle*. The military services tend to keep engine models in use longer than airlines. After the commercial market moves on to the next model, engine manufacturers have less incentive to keep improving their product that is still in the military inventory.
- *Relative size of military and commercial market*. It seems sensible to conclude that the military can benefit from commercial development and improvement if the military is a small customer relative to total commercial sales. On the other hand, if the military is a relatively large customer, it is more vulnerable than commercial customers to increases in spare parts prices. This is because the military, according to current procurement rules, may not "blacklist" a supplier for poor past performance without due process as a commercial airline can. Even if the military is a relatively small customer, if it is the largest single customer, it may still be vulnerable. Companies may argue, for example, that problems with the engine are solely related to military usage. Because there are so few precedents for commercial acquisition programs, we do not know the thresholds for "relatively small" and "relatively large" or whether these potential problems will in fact arise. The F108 and F117 engine programs should be monitored carefully to gain experience and insights into this area.

When there are no commercial counterparts, as in fighter and most bomber engines, there is still a need for government support for CIP. Figure IV-1 shows the results of a hypothetical cost-benefit analysis of CIP privatization for the J79 engine used in the F-104 and F-4 fighters and the B-58 bomber. The analysis uses data from Section III. Initially, privatization would result in budgetary savings of over $800 million as CIP is not funded. However, in later years, increased depot costs, costs of aircraft attrition, and costs of increased spare engines overtake these savings and result in a net cost of over $2 billion during the time period shown.

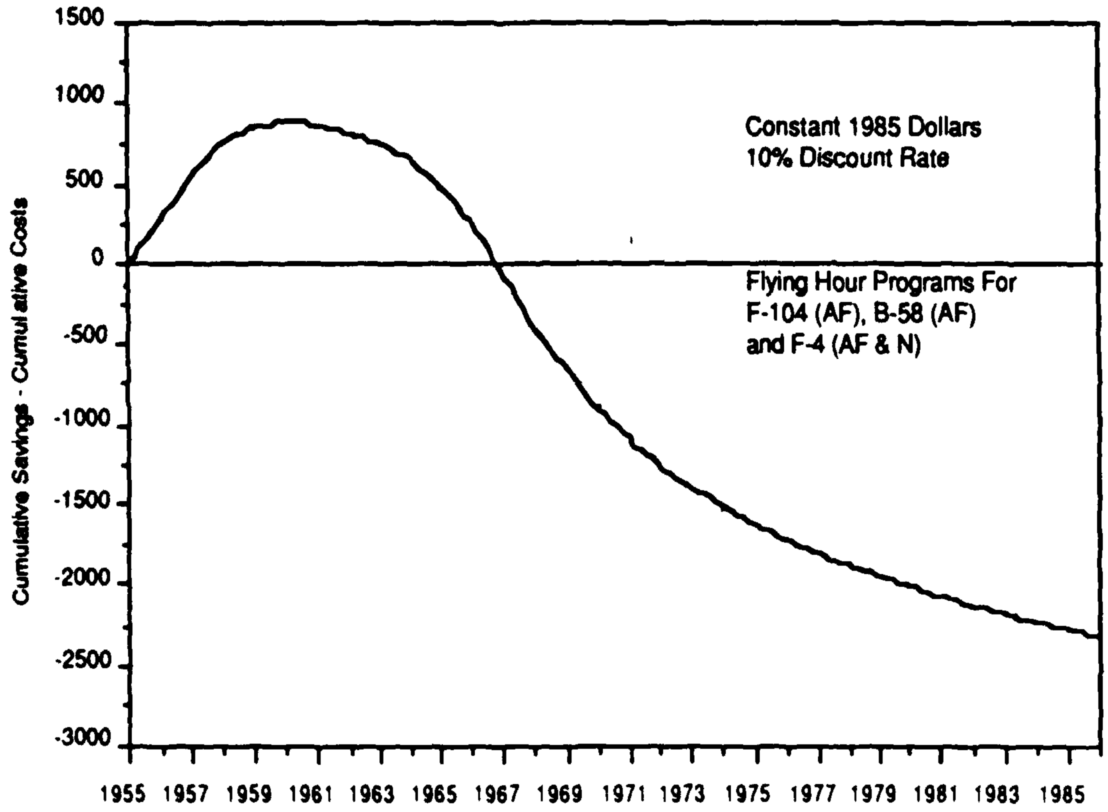

Figure IV-1. Privatization Option, J79

If the government were to privatize CIP for fighters and bombers, some limited, uncoordinated improvement activities would still have to occur through other line items or engineering change programs. Thus, the government would still bear some costs. As a general rule, however, engine manufacturers in non-competitive programs have little incentive to perform CIP activity out of their own funds. The incentive instead is to sell spare parts and move on toward the next design, not improve the current design.

2. Privatization by Time Phase

The feasibility of privatization for engines without commercial counterparts varies depending on whether the engine is in or out of production. Table IV-4 indicates the feasibility of privatization of CIP by time phase. In all cases, there is little incentive for private firms to do component improvement on military engines after the engine is out of production. The firm has no hope of making money by selling more engines. While the company is still selling spare parts, there may even be more parts breakout competition meaning less potential revenue. Thus, the company is unlikely to use its own funds to improve current models. (The only exception might be if the company designed an improvement that required a new part, and the company believed it could recoup the design cost by selling spares.) It is important to note that engines may be in use after being out of production for as long as 25 years. What is most needed at that phase in an engine life cycle is retention of performance as engines continue to go through the depot.

In non-competitive procurements, the incentives during production are the same as when the engine is out of production. The private sector is unlikely to fund CIP on its own. When there is competition in procurement, the government may have some leverage to force partial privatization in the form of cost sharing if it plans ahead.

If the engine purchase involves competition, the government may have enough leverage to force the company to share the cost of CIP. For example, it might be possible for the government to structure contracts which include component improvement in the cost of the engine purchase or as a separate fixed-price incentive line item. Companies then might have incentives to put resources into CIP in the hopes of getting a larger share of future contracts. Such a change would require changes in government procurement practices and regulations, however, to allow the government to take into account the quality of the engine and past performance, not just technical specifications. In addition, data rights are an issue in company-funded CIP. If companies fund CIP themselves, the company would own the data rights. If companies own the data rights, the government cannot break out newly-designed parts for competition. In order to protect itself, the government could

Table IV-4. Possibilities for Transitioning CIP to Private Sector by Time Phase

Time Phase	Example Engines (Aircraft)	Current Situation	Possibilities for Privatization
In Production			
• With competition in engine production and warranty	F100/F110 (F-15, F-16) F404 (F/A-18A)	Government-funded CIP. Warranty linked in contract to government-funded CIP. Some CIP competition possible as one element of contract.	Some possibility depending on contract structure, warranty.
• No competition with warranty	TF34 (A-10) T700 (UH-60, AH-64)	Government-funded CIP. Warranty linked in contract to government-funded CIP.	Little possibility. Some possibility of renegotiated warranty.
• No competition in engine production	T56 (C-130) F101 (B-1B)	Government-funded CIP unless there is a commercial counterpart.	No – no incentives unless engine has commercial counterpart. Then privatization may be feasible.
Out of Production	J57 (KC-135) J79 (F-4) TF4 (A-7)	Government-funded CIP.	No – no incentives.

write fixed-price incentive CIP contracts or try to obtain data rights under a company-funded program

Finally, we need to consider the implications of warranties for privatization of CIP. As presently constituted, warranties do not represent a substitute for CIP. They are really short-term insurance policies. Indeed, most warranty contracts assume that some level of CIP will continue throughout the program.

However, future warranties might be restructured to create better incentives, for example, by periodic renegotiation or life cycle guarantees. The engine companies would have to include such costs in their prices at the beginning of a program before they had any cost experience. This would be extremely risky. It is not or should not be the government's intent to cause a company to go bankrupt if they estimate the warranty cost poorly.

Incentive contracts or warranties constructed in innovative ways could provide incentives for the private sector to perform work now funded by CIP. For example, current law allows (but does not require) warranties that reward or penalize based on reliability, maintenance, or availability targets such as a target engine removal rate. Properly crafted, such incentive contracts or warranties might cause the private sector to consider more carefully how to design and build a system in the first place and to improve it when appropriate.

The warranties currently used by DoD are too short to provide incentives that would warrant privatization of CIP. Most warranties have been in the range of one to three years. The longest warranty period we have heard of in the course of this project is about seven to eight years (3000 TAC in the F100 and F110 engines), while the engine life cycle is likely to be 30 years or more. There are no precedents for warranties or incentive contracts for such long periods of time. This creates an incentive problem. Ideally, one would want the private sector to make efficient decisions about whether to supply spare parts to replace defective ones or to redesign the part. A company, looking at a shorter horizon, might decide that supplying spares makes sense, while the government, looking at a 30-year life cycle, would want to redesign, as CIP allows them to do. (Current Navy warranties, however, do allow the military to specify whether parts are to be replaced or redesigned.) Nevertheless, there may be room for lengthening the period for which the contractor is responsible for engine performance.

Another alternative along the same lines is contractor maintenance at fixed price - so-called "power by the hour". There have been proposals along these lines, but no examples that we are aware of. This would be tantamount to leasing engines. In this way contractors would be held accountable for performance of engines, because they would be committed to maintaining them. This option is a very attractive one with respect to incentives, but it may be strategically or politically impossible to eliminate the large networks of maintenance personnel in the services.

All of the above options deserve further exploration. Attempts to incentivize contractors have some natural limits – the services tend to put readiness first and efficiency second, while contractors work for their own survival and for maximum sales and profits. All of these options require planning early in the acquisition phase, and all require major changes in both CIP and other DoD policies. While this analysis points to some possible alternative, we did not have the time or resources to examine all combinations of possible DoD policy changes that could lead to good outcomes.

Some observers have questioned the need for CIP funding for engines that have been out in the field for a number of years, on the grounds that most CIP benefits occur early in the life cycle. We have some indications that early CIP funding is targeted toward safety of flight and correction of deficiencies, while the later CIP is targeted toward cost reduction (through durability, reliability and maintainability improvements). CIP funding does decline as the engine ages, but attempting to end support for older engines has been shown to be inappropriate in a number of cases such as the J52 in the Navy and the Army T53. The out-of-production years are those when companies are least likely to fund any CIP activity on their own.

CIP needs to be considered in the context of all policies designed to encourage engine reliability, including the development process, developmental and operational testing programs, prototypes, competition, incentive contracts, warranties, and logistics support. While we have considered these alternatives in a cursory way, it is very difficult to perform such a global analysis. Even when considering CIP on its own merits, the military services do not have the appropriate tools to analyze the value of marginal increments of CIP using uniform and rigorous assumptions.

3. Privatization by Objective or Function

One possibility is to privatize some objectives, such as reliability, while still funding others such as safety of flight. As a general rule, this would be difficult to do, since CIP tasks very often have multiple objectives. As part of the background research for this study, we asked companies to estimate what percentage of CIP funding went for each objective. They managed to do so, but with some difficulty, and their answers varied widely.

The safety-of-flight objective clearly must be achieved. When safety-of-flight problems arise, they must be resolved quickly. Government funding and control is the best way of making sure this happens. The privatization of other objectives may be feasible, but blanket privatization of non-safety objectives does not make sense because of the incentive problems described above.

C. COMPETITION FOR CIP FUNDING

DoD and Congress have mandated increased competition in defense contracting over the last several years. These initiatives have resulted in guidelines being set up for competition for off-the-shelf items and for unique items like major weapons systems. Thus, it seems useful to address competition in the context of CIP.

There have been few opportunities for competing CIP engineering and design tasks in the past because only one qualified source has been available. As a result of new approaches in engine acquisition programs, there are future situations in which competing sources for CIP may be available.

1. Status of Competition

In this section, we examine options for increasing the use of head-to-head competition involving multiple contractors for CIP tasks . The nature of CIP tasks presents formidable obstacles to competition. CIP tasks often involve specialized expertise which resides only with the developer of the engine. Because of its nature as continuing engineering and the degree to which tasks change over time, the government's focus has been to maximize the amount of improvement to the engine for a fixed budget rather than minimize the cost of a given set of tasks. (Annual CIP contracts are, however, subject to audit and review.) Nevertheless, there may be some tasks for which competition is possible.

The government might want to compete CIP tasks for five reasons:

- To achieve cost savings for specific tasks
- To achieve cost savings for engine acquisition through spreading expertise
- To increase the flow of technical ideas
- To enhance fairness in dealing with contractors.
- To obtain leverage over contractors.

Table IV-5 lists some advantages and disadvantages of competition in defense and summarizes the results of the defense competitions so far. The results of competition in acquisition programs are mixed:

- Competition appears to work well on small commodity items for which there are multiple sources.
- Competition appears to lower costs for long-term, large volume buys from multiple sources.
- Major systems competitions in the engine industry have increased contractors' responsiveness to government concerns about reliability.
- For major systems, competition is an investment decision. Government must weigh increased costs and time to initiate competition and cost of increased overhead with the possibility of lower prices over several years of purchases.
- There are many considerations in deciding whether or not to have competition.

CIP activity is not exactly like either small commodities or unique systems – it is essentially services rather than a product. But in the sense that it requires unique expertise, it is much more like the acquisition of aircraft engines, where competition is difficult, than it is like small commodities, where competition is relatively easy to establish.

Table IV-5. Results from Past Competitions in Defense

Advantages	Disadvantages	Results from Prior Competitions
Lower costs over long run in large volume buys	Delays	Competition appears to work well on small commodity items for which there are multiple sources or for which it is inexpensive to qualify a second source, and for which there will be purchases of a sufficient quantity.
Broader suppliers base	Decreased learning in split buys in the short term	
More efficient contractors	Increased logistics support base	Competition appears to lower costs for long-term, large volume buys from multiple sources.
Lower overhead costs in winner-take-all competitions	Increased overhead costs in split buys	Major systems competitions in the engine industry have increased contractor's responsiveness to government concerns about durability and reliability – e.g., F100/F110 alternate fighter engine program.
Fairness	Legal problems of data rights	
Increased contractor responsiveness to government concerns	Cost of initiating and administering - Government spending to qualify second source - Government administrative costs	For major systems, competition is an investment decision. Government must weigh increased costs and time to initiate competition and cost of increased overhead in split buys due to lower production rate with possibility of lower prices over many years of purchases e.g. F404 dual sourcing.
Larger forum for ideas		
Tighter schedules		
Decreased incentives for changes		

There are several reasons why the government might view CIP competition as disruptive. These include:

- Reduced flexibility in projects. Currently, CIP tasks are grouped into a single annual contract, and tasks often change over the course of the year or are accomplished over more than one year. With competition, the government would have to define projects more carefully initially, and might not be able to redirect effort responsively without recompeting as more knowledge becomes available in the task effort.
- Additional costs to qualify the second source and to coordinate among sources
- Not having the entire engine data base in one place
- Complication of product liability and warranty considerations
- Increased contracting lag time
- More complicated configuration control
- Poorer integration of improvements
- Poorer long-term planning
- Poorer implementation of improvements.

The government has pursued several strategies to ensure that, when multiple sources are not available, the program is run in a cost-effective manner. Within the government, the CIP program must justify itself relative to other objectives in the RDT&E budget. Within companies, many CIP tasks are formally and informally proposed. These compete within the company for the opportunity to be presented to the government to be funded. The military service allocates funding to tasks within engine programs by assessing the return on the government's investment for each alternative.

Definitions of competition in the Competition in Contracting Act suggest that, if the developer of a system is selected competitively, subsequent procurements for services, like follow-on engineering, may be counted as competition. For example, Air Force procurement of CIP for the F100 and F110 engines can be counted as competition, because the purchase of the engines was competitive. However, the Air Force has not held head-to-head competition for CIP tasks within an engine CIP effort.

The services are exploring the possibility of head-to-head competition for CIP in the future. For example, the Navy is working to maximize opportunities for competition in the F404 engine, which was developed by General Electric but will be produced by GE and Pratt & Whitney. The Navy intends to ask companies if they are interested in competing specific areas of CIP. In addition, the services are exploring the possibility of vendors and subcontractors competing directly for CIP. This may pose some problems, in that vendors might prefer selling to a prime contractor in order to retain data rights and to keep their cost data confidential. Also the potential for savings is affected to the extent that the prime contractor will have to be involved in some manner to approve any change for incorporation in the engine.

2. Options for Competition

Again, we use mission area as a framework for organizing discussion of CIP competition. Table IV-6 illustrates some possibilities for competing CIP by mission area. There are clearly areas where competition is not possible--the tanker, airlift, and support areas when commercial engines are used. Thus, the following discussion refers mainly to the bomber and fighter/attack missions, where the engines are almost completely military with no commercial counterparts.

We will examine three options for their viability:

- Competing the whole CIP program. This is not viable for most existing engines, because multiple sources are not available. In the future, if the government encourages teaming in development, then competition of the entire CIP program may be possible.
- Competing individual functions, such as testing, may be viable in existing and future programs. This option is discussed in detail below.
- Competing individual tasks, either among primes or by breaking out pieces for subcontractors, may be viable in some programs. In competitive programs, such as the F404, where there are two producers, the engine developer would dominate any competition of the total CIP package. However, there may be individual tasks on which both producers could compete, and the Navy is exploring this possibility. Even in non-competitive programs, competition is theoretically possible through breakout, in which the government deals directly with subcontractors and vendors. This option is also discussed below.

3. Competition by Function

CIP activity is not exactly like weapons system production, so results of past competitions in defense do not carry over exactly. Nor is CIP activity like toothpaste or radios or the whole array of consumer products which are sold in competitive markets. Large markets for purely military engines do not exist. On the supply side, two companies dominate, with a few smaller competitors for some items. On the demand side, the U.S.

Table IV-6. Some Possibilities for Competing CIP by Mission Area

Mission Area	Example Engines	(Aircraft)	Possibilities for Competing CIP Tasks
Strategic			
• Bomber	J57	(B-52)	
	TF33	(B-52)	
	F101	(B-1B)	
	NEW PROGRAM		None likely to arise, except for testing – lack of alternative sources.
• Tanker	J57		Where commercial market leads, CIP will probably be privatized.
	TF33	(KC-135)	
	CF6	(KC-10)	
	F108		
	[CFM56]*		
	NEW PROGRAM		Privatization would preclude competing CIP. In government-supported CIP, could compete testing.
Tactical			
• Fighter/Attack	J79	(F-4)	Possible opportunities as a result of production competitions – e.g., F100/F110, F404.
	J52	(A-6)	
	TF30	(F-111, F-14, A-4)	
	TF41	(A-7)	
	TF34	(A-10)	
	F100/F110	(F-15, F-16)	
	F404	(F/A-18, A-6)	
	NEW PROGRAM		Greatest potential in joint development programs.
• Helicopters	T53	(UH-1 AH-1)	
	T55	(CH-47)	
	T63	(OH-6, OH-58)	
	T700	(UH-60, AH-64)	
	NEW PROGRAM		Few likely to arise, except testing – lack of alternate sources.
Airlift	T56	(C-130)	
	TF33	(C-141)	
	TF39	(C-5A&B)	
	F117	(C-17)	
	[PW2040]*		
	NEW PROGRAM		Privatization would preclude competing CIP – in government-supported CIP, could compete testing.
Support	JT8D	(C-9)	
	J60	(T-39)	
	NEW PROGRAM		Privatization would preclude competing CIP. In government-supported CIP, could compete testing.

Models in brackets are commercial counterparts.

government is the dominant customer, supplemented by foreign countries. CIP is predominantly engineering and testing services which follow the production of the engine. For many CIP tasks, multiple suppliers are unlikely to come forth spontaneously and would have to be developed by the government at some cost in money and time.

Testing is a function of CIP that is commodity-like, more like production than development – e.g., it is clearly defined and repetitious. While there are high capital requirements (due to the need for a testing facility), test facilities tend to be generic. The testing contractor will still need to be supported in some way by the engine contractor providing expertise on-site to interpret test results and make decisions about deviations from the test plan. Competing testing should be considered. The question is: are savings possible that would justify the additional risks and administrative requirements? The relative importance of testing varies from program to program, but can be from 15 to 50 percent of total CIP activity in a given year.

In considering this scenario, several factors need to be analyzed, including the availability of qualified sources to compete, how the competition would occur, the costs of competition, and the benefits to be gained from competition.

To bid on a testing program, a firm would have to have a testing facility available. The two largest military engine manufacturers, GE and Pratt & Whitney, have such facilities. In addition, Allison and other smaller companies have some test facilities. Thus, depending on the scale of the test required, a competition for a particular testing program could have from two to five or more competitors. (The government also owns its own testing facilities.) It is conceivable, but not likely that other firms would wish to compete and could construct or buy testing facilities, at a cost of $9-12 million per test cell. Nevertheless, even with existing resources, testing competitions would be likely to attract more than one qualified bidder.

Engine companies other than GE and Pratt & Whitney might want to bid for testing work. While the large companies run as many as 5000 test hours per year on a single engine program, smaller companies with smaller programs might total only several hundreds of test hours on all their CIP engines. With competition, the government might have more flexibility in order to ensure that test facilities are being used more efficiently.

Traditionally, engine manufacturers have run tests on the results of their own CIP tasks as part of the CIP contract for the engine. Under competition, testing would have to be broken out in the same way that spare parts have been broken out from major procurements. This would entail some changes in procedures. The government might, for example, issue an RFP to cover all testing throughout the year (under current practice, testing is usually scheduled a year in advance), or all testing of a particular engine, and ask for bids per hour or per test. The government would also have to pay for representatives of the firm doing the CIP to observe the test and be available if problems arise during the test. Also, costs for support equipment and engine buildings and teardowns during testing will have to be considered.

There are precedents for non-developers performing engine testing. In several cases, foreign countries, in order to avoid spending hard currency, have performed tests as part of an in-kind payment for U.S. weapons. This option must be considered carefully when it involves high technology. The military services themselves conduct some engine testing.

Added costs to the government of a non-developer doing testing would include:

- Cost of support equipment for the firm doing the test
- Cost of transporting the engine, between the firm doing the CIP and the test site
- Cost of observers and consultation about problems during test
- Possibly, time delays associated with having different firms doing CIP and testing
- Cost of administering the competition--writing the RFP, evaluating the proposals, etc.

It is possible that competition will result in a lower cost to the government for testing, even if the firm doing the CIP wins the competition. Competition tends to cause companies to be more efficient than in non-competitive procurements. Other benefits which could accrue include increased objectivity in testing and a broadening of the industrial base for testing.

There are, however, some substantial risks and uncertainties for the government in competing testing. If a non-developer wins the testing competition, the engine developer would be concerned about competitors acquiring proprietary information during the test. In addition, there may be disagreements among developers and testers about the conduct of the test, and there may be increased risk of loss of the engine.

Figure IV-2 presents a hypothetical cost-benefit analysis of competition for testing for the J79 engine, using data from the example in Chapter III. The analysis assumes that testing represents 50 percent of total CIP and that the competition results in a 20 percent decline in overall testing costs, net of added government costs, resulting in a net 10 percent savings. Such savings would increase the net benefits associated with CIP. Even with these generous assumptions, the breakeven point remains almost the same as it was under the non-competitive assumption. It is also important to note that the recurring costs and delays resulting from annual testing competition are unpredictable.

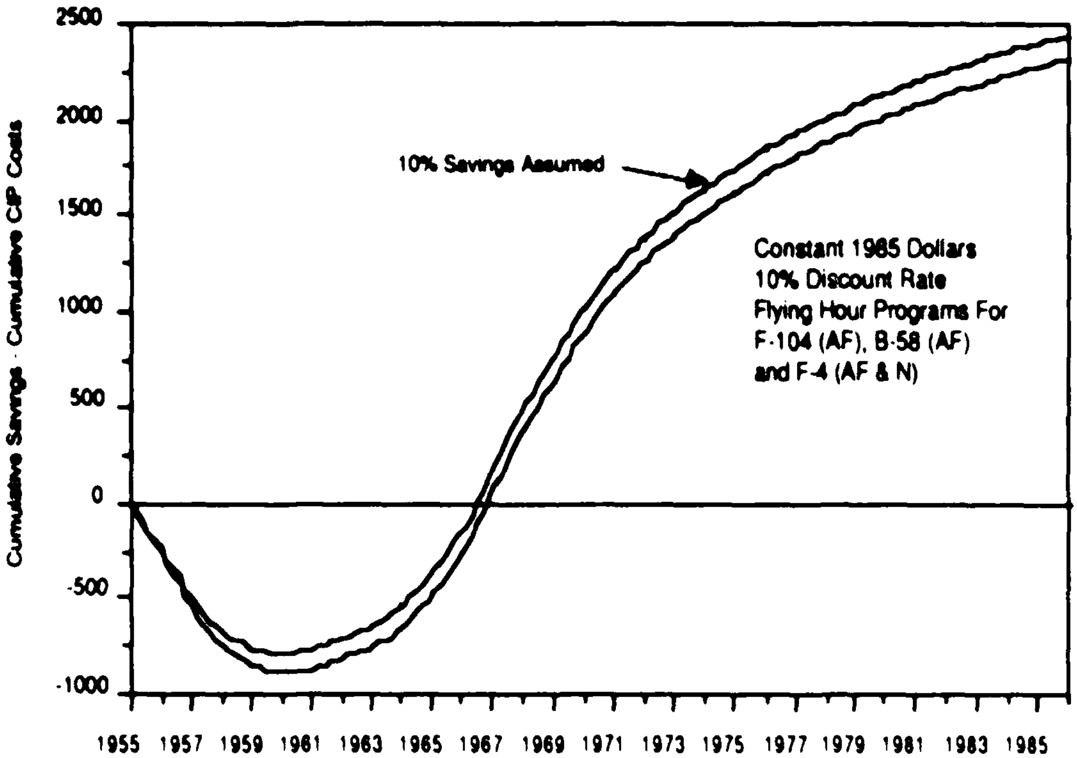

Figure IV-2. J79 Competition Scenario

4. Competition by Task

Under some competitive acquisition plans--for example the F404 dual sourcing and the T800 joint development--there would theoretically be two contractors with sufficient expertise on the engine to compete activities other than testing.

Even with two available contractors, one may have a substantial edge in any competition. In the F404, for example, GE designed the engine. While Pratt and Whitney has gained substantial knowledge from producing the engine, that knowledge may not be sufficient to make them an efficient contractor for CIP. On the T800 joint development, the contractors are specializing in different aspects of the engine. The Navy is considering competition by task for the F404. A new FADEC fuel control might be a candidate for competition.

CIP proposals for improvement of a particular engine have come only from that engine's producer. Recently, competitions in engine acquisitions have resulted in engines having multiple developers and/or producers. Thus, there are future opportunities for competition of CIP due to the availability of qualified sources.

Non-testing CIP activities require specialized knowledge. For example, design of improved parts may be more efficiently handled by the designer of the engine. On the other hand, if one believes that resources are mobile across firms, companies who wish to compete for CIP could hire away the designers. A competitor in an engine program might want to do this to enhance its knowledge of the engine in order to lower its production costs in procurement competitions for the engine, but it is unlikely that designers would move solely because of a CIP effort.

There are, however, some concerns about configuration control in an environment in which a non-developer is designing new components. How would that affect an engine warranty, for example?

To maximize the benefits of CIP competition, it should be included in the acquisition plan and should begin with the first CIP contract. Early on, incentives to minimize CIP costs are at a maximum for the companies, and the government's investment in competition has the maximum amount of time to be amortized and to pay off. Later, as engines are purchased and production runs wind down, companies have fewer incentives to bid low on CIP in order to gain an edge in production competitions.

Task definition is an important issue in CIP competition. The current method for proposing CIP tasks involves some give-and-take between the engine producer and the government. Typically, the government will state its overall goals, and the engine firm will submit a cost-plus-fixed-fee or award-fee proposal with a method for achieving those goals. If there were head-to-head competition, the government could administer such a competition by defining tasks in sufficient detail to issue an RFP and inviting firm fixed-price proposals for each specific task. This would have potential for lower costs and would also preserve government control. However, tasks which require quick responses could not be competed in this way. Also, any revisions to the task based on information gained during this task or other tasks could negate any savings from competition since any revised activity would then be sole source. Historically, over 50 percent of CIP tasks are restructured during the task.

When engine acquisition is non-competitive, there are few possibilities for CIP competition. Breakout of tasks maybe possible if there are subcontractors or vendors interested in dealing directly with the government. The government may survey these groups to determine if there is interest. Many subcontractors and vendors are likely to prefer dealing with contractors, which involves less visibility of their costs and retention of data rights, to dealing with the government. It may make more sense for the government to concentrate its competition investments where the probability of success is higher.

Table IV-7 summarizes the implications of different acquisition plans for competition.

Table IV-7. Impact of Acquisition Plan on Feasibility of CIP Competition

Acquisition Plan	Current Situation	Feasibility of Competition
Traditional Example: J79	Availability of Sources: Single source; others could be qualified Data Rights: Government	Testing competition feasible. Breakout of some tasks may be possible.
Competing Engines: F100/F110	Availability of Sources: One per engine Data Rights. Government	F100/F110 CIP budget might be included in procurement contract with cost sharing. Testing competition feasible. Breakout of some tasks may be possible at vendor level.
Dual Source: F404	Availability of Sources: Two production sources might compete on some tasks Data Rights: Government	Both could compete for tasks, with some startup costs. Testing competition feasible. Breakout of some tasks may be possible.
Commercial Model: PW 2040	Availability of Sourcess: Single development and production source Data Rights: Company	Private sector CIP. No competition.
Joint Development: T800	Availability of Sources: Two or more sources from development team	CIP program could be competed. Companies might specialize in particular areas. Breakout of some tasks may be possible.

D. OTHER METHODS OF ACCOMPLISHING CIP ACTIVITIES

Another option in considering policy changes for CIP is to examine how sustaining engineering is accomplished for other equipment. In particular, airframe and avionics equipments are of interest. There are three periods when engineering changes occur – during development, during production and when the product is out of production, but still in operational service. We focus here on engineering changes during production and when the product is out of production, but still in operational service.

The engineering change process is extremely complex. The steps in the process can vary among the military services, among programs and among equipments. There are, however, some basic elements that are applicable to all situations. All equipment (airframe, engine and avionics) has a sustaining engineering (SE) or engineering assistance to production and service (EAPS) element that is funded through an add-on to the selling price of the equipment. These funds are usually used for quality control and production problems in the factory. Field problems arising from quality control or production can be handled in this way. But when serious field problems develop, and extensive engineering, testing and manufacturing of parts for retrofit and significant changes to the production line will result, then solutions to problems are usually funded through engineering change proposals (ECPs) for airframes and avionics and through CIP for engines. The SE or EAPS funds may be used to investigate and help identify the problem in all these situations, but the engineering, testing and manufacture of kits for retrofit in the field or changes to production are all incorporated in the ECP for airframe and avionics. This is different from engines where the engineering and testing (and manufacture of any parts for testing) would be under CIP, but the manufacture of parts for retrofit, or changes to the production line, would be done by an ECP developed from the CIP work.

For airframe and avionics engineering changes, the ECP may be added to an existing production contract as a specific line item, or there may be an allocation within the current production contract from which this ECP would be able to obtain funding. When the engineering change has been developed and approved and an engineering notice is issued to execute the change, funds come from a production contract with the System Program Office to purchase kits for retrofit in the field or to introduce changes to the production floor. If a component is out of production, but still in service, a specific contractual change may be added to a contract for the purchase of spare parts with the

Systems Manager (at the Air Logistics Center in the Air Force for instance) for that component. Thus, in the airframe or avionics case, the ECP not only includes the funds for the changes to the production line and/or retrofit kits but also the engineering and testing of the change.

Airframes and avionics do not have a component improvement program which allows very rapid response to less-than-emergency problems. Particular efforts must get under contract before the engineering and testing can begin to correct a particular problem. This requires time and effort, but is manageable while the product is in production. It is more difficult to accomplish when the product is out of production. The classes of priority for engineering changes in airframe and avionics are emergency, urgent, and routine. The engine community has added categories to the three major priorities as defined in DOD STD-480A. In the case of the TF30 program they include emergency, urgent, priority, routine, deferrable, and follow-up. Definitions of EAPS and categories of priorities for airframes and avionics and the TF30 example for engines are included in the appendix.

If the problem is an emergency – e.g., safety of flight – for the airframe or avionics equipment, the contractor will usually start work immediately without any contractual obligation on the part of the military service and submit a cost proposal later. Everyone is very responsive to safety-of-flight problems, and the problem will be addressed immediately. For less-than-emergency problems, however, response times vary much more widely. For engines, CIP priorities can be reordered very quickly, and engine contractors can thus respond faster than airframe or avionics contractors can to begin work on a particular problem. The engine process has the response time advantage. Table IV-8 presents a summary of the priorities, times to accomplish first unit change, and funding sources for airframe, engine, and avionics engineering changes. It can be seen in the table that everyone will respond quite rapidly to the emergency problem dealing with safety of flight or service-revealed deficiencies that would result in grounding of the fleet.

*Table IV-8. Accomplishing Engineering Changes for Aircraft Equipments**

Equipment	Priority** (Class I Changes)	Time to Accomplish First Unit Change	Funding Source(s)
Airframe	Emergency Urgent Routine	weeks/months one to three years two to four years	Sustaining engineering or EAPS to investigate and identify problem. ECPs to perform engineering, testing and manufacturing of parts for testing and for retrofit in the field or to incorporate changes to the production line.
Engine	Emergency Urgent Priority Routine Deferrable Follow-up	days/weeks/months weeks/months months/year or more one to three years N/A N/A	Sustaining engineering or EAPS to investigate and identify problem. CIP to perform engineering, testing and manufacture of parts for test. ECPs to manufacture parts for retrofit or to incorporate changes in production line (could originate directly from from EAPS for materials, problems and production line changes).
[illegible]	Emergency Urgent Routine	weeks/months one to three years two to four years	Sustaining engineering or EAPS to investigate and identify problem. ECPs to perform engineering, testing and manufacturing of parts for testing and for retrofit in the field or to incorporate changes to production line.

[illegible] ...views with airframe, engine and avionics contractors.

[illegible] April 1978. Engine example (TF30) expanded on the three priorities in the DOD-STD. See the appendix for definitions.

AD-A182 727 POLICY OPTIONS FOR THE AIRCRAFT TURBINE ENGINE COMPONEN IMPROVEMENT PROG..(U) INSTITUTE FOR DEFENSE ANALYSES ALEXANDRIA VA J R NELSON ET AL. MAY 87 2/2

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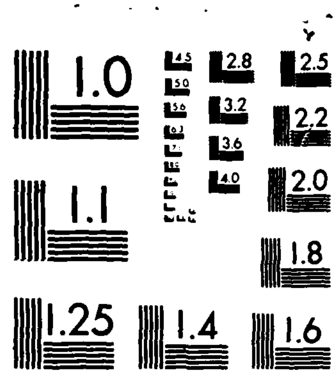

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

The engine CIP process has the edge in the less-than-emergency priorities where changes can be accomplished in months within an existing CIP contract. By contrast, airframe and avionics may take a year or more in getting through the necessary approvals to generate an ECP. In comparison with ECPs for other equipment, the Component Improvement Program clearly has an edge in getting these less-than-emergency types of changes more quickly into the equipment. The engine design change still needs an ECP to manufacture the parts for retrofit kits or to introduce a change to the production line.

Product improvements, particularly for airframes, are not always incorporated into equipment in the field immediately. Instead, improvements are put in when the equipment comes in for its regular inspection. This is particularly true for airframes. Many of the engine changes that are needed quickly in operation can be handled at base level, or a campaign can be mounted to get engines back through the depot and change out the parts. There is more flexibility in the engine change process.

In general, on the basis of discussions with airframe, engine and avionics contractors, our conclusion is that the CIP process probably saves six months to a year in accomplishing engineering changes through its ability to respond more rapidly with engineering, testing, and manufacturing efforts directed at less-than-emergency problems, and is also much more efficient in supporting out-of-production equipment.

It is unclear which approach is more cost-effective, since we were unable to obtain sufficient cost data to allow a comparison of the costs of product improvements using the airframe or avionics approach with the cost of product improvement using the engine approach. Neither approach currently lends itself to competition. The CIP process appears to be superior in terms of response time. In addition, Congress has a higher visibility into how CIP funds are spent than they do for SE, EAPS and the engineering portion of ECP funds. Finally, the CIP process involves an annual forum to set priorities for product improvement taking into account the needs of users, while the ECP process works on a case-by-case basis.

E. SUMMARY

Table IV-9 summarizes the picture for selected examples for CIP privatization and competition by mission area. As can be seen from the chart, there are no hard-and-fast rules. In each mission area, engines have different acquisition plans, which affect the possibilities for transitioning and competition. Engines acquired in the past under traditional acquisition rules and that are currently out of production need traditional CIP support. Privatization may be possible within mission areas where engines are commercial off-the-shelf items, or where they have close commercial counterparts, as in some tanker, transport, helicopter and support aircraft applications.

CIP competition clearly cannot occur when engines are being bought under commercial ground rules and there is no government-funded CIP. Competing testing activity is feasible and may or may not be cost-effective in a government-funded CIP program depending upon circumstances. In the fighter area, acquisition competitions have made two production sources available, although it is not clear that in either case there would be two qualified sources for CIP for a single engine program. This applies equally to the F100/F110 competing and the F404 dual source competition. In future programs, if there are two or more qualified sources from development, competition for CIP tasks may be feasible. The possibilities for competition in CIP should be carefully considered by the government early in the acquisition plan for each engine program.

Table IV-9. Summary of Selected Current and New Engine Programs: Possibilities for Privatization and Competition

Mission Area	Program/Engine	Privatization Candidate	Compete Within Engine CIP Candidate
Strategic			
• Bomber	B-1B/F101	No	No
	NEW PROGRAM	No***	Yes*
• Tanker	KC-135R/F108 (CFM56)	Yes	No**
	NEW PROGRAM	Yes	Yes
Tactical			
• Fighter/Attack	F-4/J79	No	No
	A-6/J52	No	No
	F-111/TF30	No	No
	A-7/TF41	No	No
	F-14/TF30	No	No
	F-15/F100; F110	No	No*
	A-10/TF34	No	No
	F-16/F100;F110	No	No
	F/A-18/F404	No	Yes**
	NEW PROGRAM	No***	Yes*
• Helicopters	UH-1, AH-1/T53	No	No
	CH-47/T55	No	No
	OH-6, OH-58/T63	Yes	No
	UH-60/T700	No	No
	AH-64/T700	No	No
	NEW PROGRAM	No***	Yes*
Airlift	C-141/TF33	No	No
	C-5A/B/TF39	No	No
	C-17/F117 (PW 2040)	Yes	No
	NEW PROGRAM	Yes	Yes*
Support	C-9/JT8D	Yes	No
	T-39/J60- JT12)	Yes	No
	TTBTS	Yes	No
	NEW PROGRAM	Yes	No

*Opportunities would occur where development teaming and/or production dual sourcing are an element of the system acquisition strategy.

**Possibilities for competing CIP as a total package may be enhanced by future competitive acquisition.

***Privatization would require major changes in acquisition strategy.

GLOSSARY

Accelerated Mission Testing (AMT) - Testing which simulates actual flight usage. Specific throttle movements by the pilot during a mission are reduced to engine test cell operations to validate changes in configuration and to determine the durability of engine parts.

Component Improvement Program (CIP) - Continuing engineering program to improve engine safety, operating envelope, durability, maintainability and reliability throughout its operational life. The program begins with acceptance of the procurement-funded aircraft and the successful completion of development qualification. It continues until the engine is no longer used in the military service. The objective of CIP is to resolve operational problems with the engine in as short a time as possible and to reduce the life cycle cost of the engine. However, it does not include sustaining engineering or engineering support to production, nor is it used for increasing performance or developing new or derivative engine models.

Direct Research and Development (R&D) Programs - That portion of the engine development cycle which is financed with R&D funds until an engine configuration has been certified acceptable for production.

Durability - The useful life of a component, assembly, or complete engine. The requirements for durability are stated in the engine model specification and verified in development testing.

Engineering Assistance to Production and Services (EAPS) - (Formerly known as Production Engineering Support (PES). EAPS is contractor engineering technical assistance to Manufacturing, Quality Control, and Product Support required to support the production phase of an engine program. EAPS will provide engineering effort to assure the manufacture of engines and spare parts including the development of ease of manufacturing changes, vendor selection, vendor technical support, and the resolution of production fit, function, and process problems.

Engine Model Derivative Program (EMDP) - The EMDP is directed to the near term exploitation of advanced technology developments which improve performance and/or durability in a derivative engine model. The EMDP development improvements are beyond the original specification requirements. (This is an Air Force program. The other services conduct similar programs under other names.)

Note: Reference is primarily Air Force Regulation 800-30.

Independent Research and Development Program (IR&D) - Technical effort within three areas: (1) basic and applied research, (2) development, and (3) system and concept formulation studies. Technical effort sponsored by or required in performance of a contract or grant is not considered IR&D. IR&D costs are normally considered to be recoverable costs and are allocated to all contracts.

Lead-the-Force (LTF) - A program to identify engine problems before they can affect force operations. This is done by accelerating flying experience on a few engines, ahead of the force average.

Mission Usage - The profile or pattern of actual engine operation, when in service. Covers such factors as ground operating time, flight operating time, and frequency and magnitude of both throttle changes and aircraft maneuvers.

Post Development Management - The management process used during production, deployment, and operational phases to identify the most cost-effective system action to take when the need for a change is identified. Post development management:

(1) Assesses the impact of changes in mission usage and maintenance actions, or the demonstrated system engineering characteristics;

(2) Implements and control introduction of configuration changes; and

(3) Maintains an engine advisory group.

Reliability - The probability that an engine will perform its intended function without any unsafe malfunction, for a specified time and in a specified environment.

LIST OF ABBREVIATIONS

AFE	=	Alternate fighter engine
AFSC	=	Air Force Systems Command
AMT	=	Accelerated mission testing
APSI	=	Aircraft propulsion system integration (R&D program)
ASD	=	Aeronautical Systems Division
ATBO	=	Average time between overhaul, hours (depot cost model)
ATEGG	=	Advanced turbine engine gas generator (R&D program)
CIP	=	Component Improvement Program (R&D program)
CPUSP	=	Current production unit selling price (depot cost model)
DoD	=	Department of Defense
EAG	=	Engine Advisory Group
EAPS	=	Engineering assistance to production and service
ECP	=	Engineering change proposal
EFH	=	Engine flying hours
EFHC	=	Engine flying hours consumed by operating fleet
EFHR	=	Engine flying hours restored to fleet by depot maintenance (depot cost model)
EMDP	=	Engine model derivative program (R&D program)
ENSIP	=	Engine structural integrity program
FAA	=	Federal Aviation Administration
FADEC	=	Full authority digital electronic control
FETT	=	First engine to test
FFR	=	Full Flight Release
FMS	=	Foreign military sales
FPQ	=	Full production qualification
FSD	=	Full scale development
IFR	=	Initial Flight Release
ILC	=	Improved Life Core (F100 engine)
IPE	=	Improved performance engine (R&D program)
IR&D	=	Independent Research and Development
ISR	=	Initial service release

JTDE	=	Joint technology demonstrator engine (R&D program)
LCC	=	Life-cycle cost
LPQ	=	Limited production qualification
MIS	=	Management information system
MQT	=	Model qualification test
MTBF	=	Mean time between failure, hours
MTBO	=	Maximum time between overhaul, hours
OCM	=	On-condition maintenance
OCR	=	Operational capability release
OMB	=	Office of Management and Budget
OPSPAN	=	Time since operational use began, quarters (depot cost model)
PFQ	=	Preliminary flight qualification
PFRT	=	Preliminary flight rating test
QMAX	=	Maximum dynamic pressure in flight envelope, lb/ft^2 (technology trend model)
RCM	=	Reliability-centered maintenance
RDT&E	=	Research, development, test, and evaluation
RFP	=	Request for proposal
RMS	=	Resource Management System
ROI	=	Return on investment
SE	=	Sustaining engineering
SFCMIL	=	Specific fuel consumption at military thrust, sea-level static (SLS), lb/hr/lb thrust (technology trend model)
SOW	=	Statement of work
SRD	=	Service-revealed deficiency
TEMP	=	Maximum turbine inlet temperature, °R (technology trend model)
THRMAX	=	Maximum thrust (with afterburner if afterburner configuration), SLS, lb. (technology trend model)
TOA	=	Time of arrival (technology trend model)
TOA26	=	Time of arrival of demonstrated performance obtained from model derived using 26 military turbojet and turbofan engines, calendar quarters (technology trend model)

TOTPRS = Pressure term (product of QMAX x pressure ratio), lb/ft^2 (technology trend model)

TTBTS = Tanker transport bomber training system

UER = Unscheduled engine removal

WGT = Weight of engine at configuration of interest, lb. (technology trend model)

ΔTOA26 = TOA26-MQTQTR, calendar quarters (depot cost model)

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APPENDIX

*Table A-1. Military Equipment Priority Classifications**

4.5 *Class I engineering change priorities.* A priority shall be assigned to each Class I ECP based upon a selection from the following definitions. The priority will determine the relative speed at which the ECP is reviewed and evaluated, and at which the engineering change is ordered and implemented. The proposed priority is assigned by the originator and will stand unless the procuring activity has a valid reason for changing the processing rate.

4.5.1 *Emergency.* An emergency priority shall be assigned to an engineering change proposed for either of the following reasons:

a. To effect a change in operational characteristics which, if not accomplished without delay, may seriously compromise the national security.

b. To correct a hazardous condition which may result in fatal or serious injury to personnel or in extensive damage or destruction of equipment. A hazardous condition usually will require withdrawing the item from service temporarily, or suspension of the item operation, or discontinuance of further testing or development pending resolution of the condition.

4.5.2 *Urgent.* An urgent priority shall be assigned to an engineering change proposed for any of the following reasons:

a. To effect a change in operational characteristics which, if not accomplished expeditiously, may seriously compromise the mission effectiveness of deployed equipment.

b. To correct a potentially hazardous condition, the uncorrected existence of which could result in injury to personnel or damage to equipment. A potentially hazardous condition compromises safety and embodies risk, but within reasonable limits, permitting continued use of the affected equipment provided the operator has been informed of the hazard and appropriate precautions have been defined and distributed to the user.

c. To meet significant contractual requirements (e.g., when lead time will necessitate slipping approved production, activation or construction schedules if the change were not incorporated).

d. To effect an interface change which, if delayed, would cause a schedule slippage or increase cost.

e. To effect, through value engineering or other cost reduction efforts, net life cycle savings to the Government of a total of more than one hundred thousand dollars, where expedited processing of the change will be a major factor in realizing these lower costs.

4.5.3 *Routine.* A routine priority shall be assigned to a proposed engineering change when emergency or urgent is not applicable.

Source: DOD-STD-480A, 12 April 1978, Paragraph 4.5.

Table A-2. Engineering Assistance to Production and Service (EAPS) on TF30 and Other Mature Military Engines

Expenditures made by Engineering and Operations in the area of Engineering Assistance to Production and Service (EAPS) covers that effort required to support engine and spare parts production, spare parts sales, and to investigate problems arising in the field on delivered engines to determine if further investigation and resolution is required under the Product Support Program. This effort also includes review and analysis of airframe manufacturer's test program data.

The specific types of effort classified as EAPS, include:

- Technical assistance to solve production and quality control problems.
- Liaison with manufacturing areas (i.e., Production, Quality Control, and vendors) and the customer and/or airframe manufacturers. Liaison with the customer and airframe manufacturer is maintained through divisional groups such as the Product Support Department and P&WA service representatives.
- Initiation and/or coordination of engineering changes affecting manufacturing processes which will reduce costs or further improve manufacturing capability. This includes design, procurement and test of sample hardware. Engine test work would be conducted within the Product Support Program.
- Performing services to define and solve problems in the general areas of chemical and metallurgical production processes, physical and chemical analyses of engine parts returned from Production or the field and production engine performance analysis.
- Assessment of engine reliability, and analysis and reporting of these assessments as required by production engine contracts.
- Technical assistance required to permit updating and correction of the engine technical publications (shop and maintenance manuals).

Table A-3. TF30 Engine Program Priority Classifications

Code	Description
E	*EMERGENCY* – Flight safety item only – all possible effort at the expense in effort and time of all other programs if and as required. Specific target dates for completion should be specified and AFSC and NAVAIRSYSCOM should be continually advised of any delays.
U	*URGENT*– Potential flight safety items which do not necessitate EMERGENCY classification – items which have serious impact on field operations and logistic support – all possible effort at the expense of all other programs if and as required except EMERGENCY programs. Target dates for completion should be specified and any lengthy delays should be made known to AFSC and NAVAIRSYSCOM.
P	*PRIORITY* – Items which prove of considerable values to Air Force and Navy in reliability, maintainability, durability, or economy – to be accomplished on an expeditious and continuing basis for earliest completion without interference to EMERGENCY and URGENT programs. Milestone dates should be estimated and revised as necessary in reports and TF30 Program Reviews.
R	*ROUTINE*– Items which will be pursued to the extent that higher priority programs permit – generally following programs will fit into this or DEFERRABLE category unless AFSC or NAVAIRSYSCOM requirements dictate higher priority (1) cost reduction items, (2) performance improvements, (3) desirable but not essential improvements. Milestone dates should be estimated and revised as necessary in reports and TF30 Program Reviews.
D	*DEFERRABLE* – First items to be delayed or dropped in case of shortage of personnel in the engine area of investigation, shortage of test time or opportunity to accomplish, or actual or predicted shortage in current funding. Cars should be taken in commencing and conducting these programs to avoid waste due to on-again off-again potential. In general, these programs should be undertaken primarily toward the end of the contract year when adequacy of funding has become assured.
F	*FOLLOW-UP* – Items for which there is not yet sufficient evidence to substantiate the need for further engineering and development effort, in light of the justification criteria for Engineering Change Proposal approval. Action on these items will be limited to compilation of additional evidence relating to the problem until assignment of a higher priority classification is agreed upon. This classification also includes items on which engineering action has been completed but where continued monitoring of service experience is desired in order to confirm the effectiveness of the correction.

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