Audit Report

OFFICE OF THE INSPECTOR GENERAL

OBTAINING THE MAXIMUM LIFE FROM F-404 JET ENGINE COMPONENTS

Report No. 94-133 June 14, 1994

Department of Defense

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June 14, 1994

MEMORANDUM FOR ASSISTANT SECRETARY OF THE NAVY (FINANCIAL MANAGEMENT)

SUBJECT: Audit Report on Obtaining the Maximum Life from F-404 Jet Engine Components (Report No. 94-133)

We are providing this report for your review and comments. This report resulted from our Audit of Jet Aircraft Engine Durability (Project No. 3LB-5007). It discusses actions the Navy can take to obtain the maximum life from F-404 engine components.

Comments to a draft of this report were requested from the Assistant Secretary of the Navy (Financial Management) on March 17, 1994. As of June 6, 1994, comments have not been received. DoD Directive 7650.3 requires that all recommendations be resolved promptly. Therefore, we request that the Assistant Secretary of the Navy (Financial Management) provide comments on the recommendations and monetary benefits by August 15, 1994.

Recommendations and potential monetary benefits are subject to resolution in accordance with DoD Directive 7650.3 in the event of nonconcurrence or failure to comment. The report identified no internal control weaknesses.

The courtesies extended to the audit staff are appreciated. If you have any questions on this audit, please contact Mr. Christian Hendricks, Program Director, at (703) 692-3414 (DSN 222-3414) or Mr. James L. Kornides, Project Manager, at (703) 692-3420 (DSN 222-3420). Copies of the final report will be distributed to the organizations in Appendix D. The audit team members are listed on the inside back cover.

Robert J. Lieberman
Assistant Inspector General
for Auditing

This special version of the report has been revised to omit source selection and contractor confidential or proprietary information.

Office of the Inspector General, DoD

Report No. 94-133 **June 14, 1994**
(Project No. 3LB-5007.03)

OBTAINING THE MAXIMUM LIFE FROM F-404 JET ENGINE COMPONENTS

EXECUTIVE SUMMARY

Introduction. This report resulted from our Audit of Jet Aircraft Engine Durability (Project No. 3LB-5007). Additional issues related to the durability of jet aircraft engines are or will be addressed in separate reports. The F-404 engine was designed for the U.S. Navy by the General Electric Company and is used in the Navy's F/A-18 aircraft. At the time of audit, the Navy anticipated spending $1.07 billion over the 6-year period, FYs 1994 through 1999, to replace components in its F-404 engines.

Objectives. The objective of this part of our audit was to evaluate whether the Navy obtained the maximum life from its F-404 engine components. In addition, we evaluated the effectiveness of applicable internal controls.

Audit Results. The Navy replaced F-404 life-limited engine components even though a high probability (99.9 percent) existed that the components had additional life remaining. We estimated that by using an inspection program to manage the engines, the Navy could avoid the procurement of $75.5 million of replacement components and achieve a net savings of $52.4 million over the remaining life cycle of the F/A-18 aircraft (15 years).

Internal Controls. The audit identified no material internal control weaknesses and no weaknesses in implementation of the DoD Internal Management Control Program. See Part I for details of internal controls assessed.

Potential Benefits of Audit. A monetary benefit of $23.1 million will be realized during the next 6 years by extending the lives of components in the Navy's F-404 engines (Appendix C).

Summary of Recommendation. We recommend that the Commander, Naval Air Systems Command, establish a program of periodic inspections of F-404 engine components to optimize engine component life and to ensure efficient use of resources.

Management Comments. Comments to a draft of this report were requested from the Assistant Secretary of the Navy (Financial Management) but none were received. We request comments to the final report from the Navy by August 15, 1994.

Table of Contents

This report was prepared by the Logistics Support Directorate, Office of the Assistant Inspector General for Auditing, Department of Defense.

Part I - Introduction

Background

The F-404 engine was designed and built by General Electric Aircraft Engines, a division of the General Electric Company. Pratt and Whitney, a unit of United Technologies Corporation, is the second-source manufacturer of the F-404 engine. The F-404 engine is used in the Navy's F/A-18 aircraft. From 1976 through 1993, the U.S. Navy procured 1,910 F-404 engines from General Electric and 215 engines from Pratt and Whitney, valued at approximately *.

In 1992, General Electric updated its analyses of the materials used in the F-404 engine components and reevaluated the stresses that the components receive under different mission profiles. Based on its analyses, General Electric recommended that the Navy lower the life limits on life-limited components in the engine. The Navy accepted the limits that General Electric recommended; and in June 1993, the Navy published a step-down plan (a plan to phase in the new limits but avoid large numbers of grounded aircraft) and began purchasing additional spare components with the intention of fully implementing General Electric's new life limits by the end of FY 1994.

At the time of audit, the Navy anticipated spending $1.07 billion over the 6-year period, FYs 1994 through 1999, to replace components in its F-404 engines. The Navy had anticipated spending $330.3 million during the 6-year period to replace components based on the original life limits for components in the F-404 engine. The new limits resulted in a requirement to replace parts sooner and a need for $739.4 million in additional funding over the 6-year period.

Objectives

The objective of this part of our audit was to evaluate whether the Navy obtained the maximum life from its F-404 engine components. The audit also evaluated the effectiveness of applicable internal controls.

*Contractor confidential or proprietary data has been deleted.

Scope and Methodology

Review of Records. We reviewed and evaluated DoD and contractor records related to engine component life management that were prepared between January 1983 and August 1993. We also interviewed cognizant Navy F/A-18 engine program office personnel, officials at General Electric and Pratt Whitney, and personnel at the Defense plant representative offices about the methods used to manage engine components. We did not validate the accuracy of computer-processed data that we obtained from the Navy's Parts Life Tracking System. The data were used in our analysis of the life obtained from F-404 engine components.

Auditing Standards. This economy and efficiency audit was made from September 1992 through February 1994 in accordance with auditing standards issued by the Comptroller General of the United States for economy and efficiency audits, as implemented by the Inspector General, DoD. Organizations visited or contacted during the audit are in Appendix D.

Internal Controls

Controls Assessed. We evaluated internal controls over the use of Navy engine components, including the method the Navy used to ensure that it obtained the maximum useful life from its F-404 engine components. We also reviewed implementation of the DoD Internal Management Control Program as it relates to the audit objective.

Internal Control Weaknesses. The internal controls over the use of Navy engine components were deemed to be effective. The Navy used components up to their analytically predicted life limits. That procedure was consistent with the Navy's system of internal controls over aircraft maintenance. The audit identified a method that the Navy can use to extend F-404 engine components beyond their analytically predicted life limits. Details of the method are discussed in Part II of this report. No deficiencies were noted in the Navy's implementation of the DoD Internal Management Control Program as it related to the audit objective.

Prior Audits and Other Reviews

We issued two prior audit reports on jet aircraft engine durability issues. Inspector General, DoD, Report No. 94-041, "Navy Warranties for the F-404 Jet Aircraft Engine," February 14, 1994, indicated that although the Navy invoked the warranty provisions to obtain reimbursement for the life it will not achieve from nine defective F-404 engine components, it had not invoked the warranty provisions to obtain compensation (including redesign costs) for other defective components that are covered by warranty. As a result, the Navy can seek an estimated * of additional compensation from General Electric for replacement and redesign of engine components. We recommended that the Commander, Naval Air Systems Command, invoke the provisions of the warranty that require General Electric to redesign or replace all F-404 engine components that are defective. The Department of the Navy agreed to take the recommended actions.

Inspector General, DoD, Report No. 94-045, "Life Reductions of T700 Aircraft Engine Components," February 25, 1994, indicated that at the time of audit, Army and Marine Corps operational units were flying a small number of aircraft (78 helicopters) with T700 engine components that had exceeded the manufacturer's revised recommended interim life limits. If the interim limits are proven to be correct, possible failure of the engine components could result in damage to the aircraft and loss of life. We recommended that the Army and the Navy take quick action to alert field units of General Electric's overall reduction in recommended life limits for T700 engine components and that they discontinue flying aircraft with T700 engine components that have reached the new interim life limits until a final engineering decision is made regarding acceptance of the limits. The Army Assistant Deputy Chief of Staff for Logistics nonconcurred with the recommendations and indicated that the Army had completed its assessment and that the General Electric's revised life limits would not be used. The Assistant Secretary of the Navy (Research, Development, and Acquisition) nonconcurred with the recommendations and indicated that the Navy was addressing the issue by collecting data on aircraft mission profiles and inspecting fleet (engine) hardware during routine analytical maintenance actions.

*Contractor confidential or proprietary data has been deleted.

Part II - Finding and Recommendation

Extending the Lives of F-404 Engine Components

The Navy replaced F-404 life-limited engine components at the manufacturer's recommended intervals even though a high probability (99.9 percent) existed that they had additional life remaining. The condition existed because the Navy had not established an inspection program to assist it in managing the life of engine components. The Navy perceived that such a program would be too costly. We estimated that by using an inspection program (similar to programs used on other DoD aircraft engines) to manage the engines, the Navy could avoid spending $52.4 million in the next 15 years (the remaining life cycle of the F/A-18 aircraft) to replace components.

Background

Historically, a variety of factors have affected the predictions of the lives of aircraft engine components. Those factors, the lack of information about the durability of new materials used to make components, flaws in the component design and manufacturing processes, and the changing missions of DoD aircraft, made predicting the life of components difficult, which usually resulted in the formation of conservative estimates of the component life limits. The conservative limits provided a margin of safety, but did not ensure efficient use of engine components.

In the early 1980s, to maximize the full life of an engine component and to maintain safety, the Air Force and a DoD contractor (Pratt and Whitney) developed an inspection program entitled, Retirement for Cause. Under the concept, an engine component is removed from service when it incurs quantifiable damage, rather than when an analytically determined minimum design life is reached. Inspections of components at the completion of their design life reveals whether quantifiable damage exists or whether the part has remaining life. Parts that are not damaged remain in service for predetermined intervals and are periodically inspected for quantifiable damage.

Since the early 1980's, the concept has been used to successfully extend the lives of components in the F-100 engines that are used in F-15 and F-16 aircraft. Information obtained from the Air Force indicated that it anticipates that $1.2 billion will be avoided by the year 2005 through implementation of Retirement for Cause on the F-100 engine.

Retirement for Cause methodology is generic and has direct applicability to the life-limited components of all aircraft engines.

Navy Management of F-404 Engine Components

The Navy used a time limits method of managing its F-404 engine components, which resulted in premature replacement of components. Use of an inspection program similar to the Air Force's Retirement for Cause program would result in significant savings in component parts over the remaining 15 years of the F/A-18 aircraft life cycle.

Under the time limits method, Navy maintenance personnel retired life-limited components of F-404 engines when the components reached the end of their analytically predicted life. For example, if a component had a predicted life limit of * , Navy maintenance personnel retired the part when it reached * . Components with no life limits were retired on an as needed basis, which Navy maintenance personnel determined.

Using the time limits method, Navy maintenance personnel frequently retired F-404 engine components from service that had additional life remaining. This occurred because life predictions for F-404 engine components were based on a worst case scenario (1 in 1,000 components was defective at the end of the projected lives). However, in retiring 1,000 components because 1 may be flawed, the remaining life of the 999 good components (99.9 percent) was not used.

Inspections of F-404 Engine Components. The Navy's F-404 engine management philosophy did not include a program to inspect F-404 engine components to determine whether they could remain in service beyond the predicted life limits. Navy maintenance personnel indicated that they were aware of the engine inspection program (Retirement for Cause) used by the Air Force but did not pursue a program for the F-404 engine because they believed that an inspection program would not be cost-effective. However, the Navy had not performed any analysis of the cost-effectiveness of the use of an inspection program. We believe that additional component life exists in many of the F-404 engine components and that an inspection program would be cost-effective.

Additional Component Life. Information obtained from the Navy indicates that the Navy can safely extend the lives of 15 of the 23 life limited components in the engine beyond their current life-limits if periodic inspections of the components are made.

*Contractor confidential or proprietary data has been deleted.

Navy maintenance personnel indicated that an F-404 engine durability and damage tolerance assessment was performed in the late 1980s. The assessment provided information about how fast a crack will propagate in an engine component's metal; and, how that information can be used for making decisions about the remaining life of components. An assessment also includes information about the components' tolerance of cracks (how long a component could continue to function despite the presence of a crack in it). The Navy indicated that it determined through the assessment that the crack propagation life (time between detection of a crack and failure of the component) of the F-404 engine components ranged from * to * .

According to Air Force studies of crack propagation, if a crack exists in a component at the completion of its predicted life, and the crack is not detectable using inspection equipment, the part is usable for a minimum life before the crack grows to a size that causes the component to fail. Using the Navy's data we concluded that if an F-404 component does not contain a detectable crack at the end of its predicted life, a minimum of * to * (depending on the component) of residual life remains in the component.

Additionally, past Navy use of the engine components has demonstrated that additional life is available beyond the revised limits. The Navy's engine component usage records (as of June 1992) indicated that before the reductions in the projected lives of F-404 engine components, the Navy had flown many components well beyond their life limits. For example, Navy records indicated that, before the 1992 revisions to the life limits, 1,643 (99 percent) of 1,647 of the F-404 engine's stage 1 fan disks had flown for at least * (or * beyond the current life limit of *) before being retired.

Other critical rotating components were also flown well beyond their life limits before the limits were revised. Specifically, all 1,647 of the stage 2 fan disks, and 1,641 (99 percent) of 1,647 stage 3 fan disks were flown more than * beyond their current limits. Records on 1,629 stage 3 disks in the compressor module and 1,639 disks in the low pressure turbine module indicated that 1,591 (98 percent) of the compressor disks and 1,498 (91 percent) of the turbine disks were flown at least * beyond their life limit.

Although the crack propagation rates for components in the F-404 engine and the Navy's experience with the components have demonstrated that additional life is available in many components in the engine, Navy maintenance personnel believe that use of an inspection program to realize additional life from components would be too costly to the Navy.

*Contractor confidential or proprietary data has been deleted.

Cost of Assessing Components.

Costs of an Inspection Program. We evaluated the cost of establishing and operating an inspection program at the Navy's east and west coast F/A-18 intermediate maintenance facilities in California and South Carolina and the Navy's F/A-18 aviation depot in Florida. We concluded that the Navy would incur significant costs to procure equipment for the inspections and to inspect the components. However, those costs would be outweighed by the benefits of the inspection program.

Equipment. According to Navy maintenance personnel, three eddy current machines (nondestructive inspection machines that use an electrical current to detect flaws in metal) and their associated engine probes would be required to inspect engines for damage (cracks). One set of the inspection equipment would be needed at the F/A-18 aviation depot and one set at each of the two intermediate maintenance facilities. Navy personnel estimated that the equipment required to establish an inspection program would cost about $700,000 per set or $2.1 million for the three sets required.

Labor. In addition to the investment in equipment, Navy maintenance personnel estimated that 200 hours of labor would be incurred to perform a 1-time inspection of each component in each engine. We estimated that the inspections performed over 13 years (1996 through 2008 - we allotted 2 years for the Navy to set up the program) would cost $21 million. Our estimate was based on the cost of inspecting each component in the F-404 engine at * intervals (minimum time between inspections based on crack propagation rates of * to *) over 13 years. We estimated that the life cycle cost of establishing and operating an inspection program was $23.1 million (Appendix A).

Benefits of an Inspection Program. We estimated that the Navy could avoid the procurement of $75.5 million of replacement components and consumables and achieve a net savings of $52.4 million over the remaining life cycle of the F/A-18 aircraft (15 years) by extending the lives of 15 of the 23 F-404 engine life-limited components. A breakout of the F-404 components that we believe can be extended beyond their predicted lives through an inspection program and the estimated potential benefits achievable by extending each component is in Appendix B. The investment required to establish and operate an inspection program ($23.1 million) will be offset by the benefits of longer component life ($75.5 million over 15 years), or a net of $52.4 million. Approximately $23.1 million of the net potential monetary benefit will occur over the next 6 years (Appendix C). Additionally, Navy maintenance personnel indicated that the Navy does plan to use an inspection program on its F-414 engine, which is being developed for use on the modified F/A-18 aircraft. The nondestructive inspection equipment purchased for the F-404 engine, and skill and expertise developed through the inspections of F-404 engine components, will be transferrable to the F-414 engine.

*Contractor confidential or proprietary data has been deleted.

Conclusion

Retirement for Cause has been successfully used to obtain residual life from components in engines used in Air Force fighter aircraft. In addition to the direct life cycle cost savings associated with the concept (the savings would accrue from the longer use of components that would ordinarily be retired and replaced by new components), users of the concept have determined that inspections have enhanced safety by improving the understanding of the component capabilities. Further, users have determined that other monetary benefits will accrue, including reduced use of strategic materials, reduced energy required to process new components, and reduced space and administrative requirements associated with provisioning components.

Although Navy maintenance personnel perceived that the use of an inspection concept would be costly, their perception was not supported by any technical study or life cycle cost analysis. Additionally, although implementing a program such as Retirement for Cause, or some variation of it, would represent a change in the Navy's philosophy of maintaining engines, we believe it would greatly enhance the probability that each component would be used to the full extent of its safe life and thereby reduce the requirement for replacement components, while maximizing the Navy's return on its investment in engine components.

Recommendation for Corrective Action

We recommend that the Commander, Naval Air Systems Command, establish a program of periodic inspections of F-404 engine components (similar to the Retirement for Cause program used on other DoD aircraft engines) to optimize the life obtainable from each F-404 engine component and to ensure the most efficient use of resources.

Management Comments

We provided a draft of this report to the Assistant Secretary of the Navy (Financial Management) on March 16, 1994. As of June 6, 1994, we had not received formal comments. We request that the Assistant Secretary of the Navy (Financial Management) provide comments on this final report by August 15, 1994.

Part III - Additional Information

Appendix A. Investment Required to Perform Inspections of F-404 Engine Components at the End of Their Recommended Life

Capital Investment	6-Year Cost[1]	15-Year Cost[1]
Nondestructive inspection equipment[2]	$2,100,000	$2,100,000
Life Cycle Inspections		
Cost of inspections of components[3]	9,680,954	20,975,400
Total	$11,780,954	$23,075,400

[1] Includes 2 years to set up an inspection program during which no inspection expenses would accrue.
[2] The estimate was furnished by Navy personnel and includes the purchase of three fully automated eddy current inspection machines ($700,000 each) for use at one depot and two intermediate maintenance facilities.
[3] The estimate is based on the labor hours required to inspect components (the estimate was provided by Navy maintenance personnel) and the cost associated with up to 3 inspections of 1,626 engines (200 hours of labor per engine at a labor rate of $21.50 per hour).

Appendix B. Estimated Life Cycle Costs That Can Be Avoided by Implementing an Inspection Program on Life-Limited Components in the F-404 Engine[1]

Life-Limited Components	Minimum Extension of Life (Hours)	Cost Avoidance Components and Consumables 6 Years	15 Years
Fan Module			
Stage 1 Fan Disk	*	$ 3,775,802	$ 8,180,906
Stage 2 Fan Disk	*	5,189,877	11,244,734
Stage 3 Fan Disk	*	4,642,016	10,057,702
Aft Shaft	*	1,225,045	2,654,266
High Pressure Compressor			
Forward Spool P01/2	*	2,617,701	5,671,687
Forward Shaft	*	1,028,486	2,228,385
Stage 3 Disk	*	1,578,495	3,420,074
Aft Spool	*	4,039,140	8,751,470
High Pressure Turbine Module			
Rotor Air Seal	*	802,291	1,738,298
Forward Cooling Plate	*	1,927,295	4,175,807
HPT Disk	*	3,025,849	6,556,006
Aft Cooling Plate	*	962,034	2,084,409
Low Pressure Turbine Module			
Forward Air Seal	*	744,880	1,613,907
Disk	*	1,960,529	4,247,814
Torque Cone Shaft	*	1,329,699	2,878,844
Total Cost Avoidance		$34,849,139	$75,504,309

[1] The 6-year and 15-year calculations include 2 years to set up an inspection program during which no cost would be avoided. The calculation considers the age of each of the F/A-18 aircraft in the inventory, and the components in the engines that will be needed to support the aircraft until it is retired from the inventory at the end of its 15 year life. Each component would be inspected at the completion of its published life limit and every * thereafter. The components would be extended only if they are found to be in good condition. Fewer replacement components and consumables will be required due to the added use obtained from each component.

*Contractor confidential or proprietary data has been deleted.

Appendix C. Summary of Potential Benefits Resulting From Audit

Recommendation Reference	Description of Benefit	Type of Benefit
Recommendation	Economy and Efficiency. The Navy can extend the lives of life-limited F-404 engine components and reduce maintenance costs.	Funds put to better use. A monetary benefit of $23.1 million will be realized during the next 6 years (from the Defense Business Operations Fund, Appropriation 97X4930.NCIA) by implementing the recommendation.*

*Monetary Benefits Achievable Over the 6-Year Future Years Defense Plan by Inspecting and Extending the Life of Components (figures in millions)

Avoidance of Parts and Consumables		$34.8
Less: Investment and Maintenance Costs		
Equipment	$2.1	
Inspection	$9.6	
Subtotal		11.7
Total Benefit		$23.1

Appendix D. Organizations Visited or Contacted

Office of the Secretary of Defense

Office of the Assistant Secretary of Defense (Production and Logistics), Washington, DC

Department of the Navy

Naval Air Systems Command, Washington, DC
Naval Aviation Depot, Jacksonville, FL
Naval Air Warfare Center, Trenton, NJ
Naval Aviation Supply Office, Philadelphia, PA

Other Defense Organizations

Defense Plant Representative Office, General Electric, Cincinnati, OH
Defense Plant Representative Office, Pratt and Whitney, West Palm Beach, FL

Non-Defense Organizations

NASA, Lewis Research Center, Cleveland, OH
General Accounting Office, Washington, DC

Congressional Committees

Senate Appropriations Committee Staff Members, Washington, DC

Contractors

General Electric, Washington, DC
General Electric Aircraft Engines, Cincinnati, OH
General Electric Aircraft Engines, Lynn, MA
Pratt and Whitney, West Palm Beach, FL

Appendix E. Report Distribution

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- Senate Subcommittee on Defense, Committee on Appropriations
- Senate Committee on Armed Services
- Senate Committee on Governmental Affairs
- House Committee on Appropriations
- House Subcommittee on Defense, Committee on Appropriations
- House Committee on Armed Services
- House Committee on Government Operations
- House Subcommittee on Legislation and National Security, Committee on Government Operations

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