AFAPL-TR-77-18

AD B022460

YJ101 - YF-17 AIRCRAFT PROTOTYPE DEVELOPMENT SUMMARY

AIRCRAFT ENGINE GROUP
GENERAL ELECTRIC COMPANY
LYNN, MASSACHUSETTS

JANUARY 1977

TECHNICAL REPORT AFAPL-TR-77-18
Final Report for Period March 1972 – December 1975

DDC FILE COPY

Distribution limited to U.S. Government agencies only; Test and Evaluation; December 1975. Other requests for this document must be referred to AFAPL/TBD.

DDC
RECEIVED
OCT 20 1977
B

AIR FORCE AERO-PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This final report was submitted by General Electric Company, under Contract F33657-75-C-0010. This effort was sponsored by the Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio under Project 1220, Task 122001 and Work Unit 12200101 with Mr. Roger L. Spencer/TBD as Project Engineer. Mr. George Rapp of General Electric Company was technically responsible for the work.

Distribution limited to U.S. Gov't. agencies only; Test and Evaluation, December 1975. Other requests for this document must be referred to AFAPL/TBD, WPAFB, Ohio 45433.

This technical report has been reviewed and is approved for publications.

Roger L Spencer

ROGER L. SPENCER,
Project Engineer

J. FRANKLIN MONTGOMERY
Program Manager

REYNOLD E. FITZSIMMONS, Lt Col, USAF
Chief, Engine Development Branch
Turbine Engine Division

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: AFAPL-TR-77-18	2. GOVT ACCESSION NO. / 3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): YJ101-YF-17 Aircraft Prototype Development Summary.	5. TYPE OF REPORT & PERIOD COVERED: Final Report. March 72 - Dec 75
	6. PERFORMING ORG. REPORT NUMBER: R77AEG012
7. AUTHOR(s): G.G. Lail, J.H. Pennell	8. CONTRACT OR GRANT NUMBER(s): new F33657-75-C-0010
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Aircraft Engine Group, General Electric Company, Lynn, Massachusetts	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 63240F, 1220, 01, 122001, 12200101
11. CONTROLLING OFFICE NAME AND ADDRESS: AFAPL/TBD, WPAFB, OHIO 45433	12. REPORT DATE: Jan 1977
	13. NUMBER OF PAGES: 49
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 56p.	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to U.S. Government Agencies only; Test and Evaluation; December 1975. Other request for this document must be referred to AFAPL/TBD.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

DDC
RECEIVED
OCT 20 1977
B

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Turbojet, Development, Prototype, Summary, Operational, Aircraft, Life, Maintainability, Technology

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In the time period from 1970 to early 1975, the Air Force funded development of the YJ101 prototype engine for use in Northrop, YF-17, Lightweight Fighter Prototype. The engine passed a Prototype Preliminary Flight Rating Test (PPFRT) in early 1974. Flight testing of the YF-17 with YJ101

(Continued on reverse)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

403 389

20. ABSTRACT (cont'd)

engines was terminated in early 1975 after a total of 288 aircraft flights for a total of 691 engine flight hours and 2455 total engine test hours.

At the completion of the YJ101 Prototype Development Program the USAF funded a one year Continuing Engineering Program. The purpose of this program was to organize and rationalize prototype engine development experience and data into sound technical programming and fiscal information and to investigate the fundamentals of engine development practices. This report summarizes the results of the earlier Prototype Development effort and the flight test program and discusses the results and conclusions of the Continuing Engineering Program.

ACCESSION
NTIS
DDC
BY
DISTRIB
Dist.
B

PREFACE

During the period from 1970 to early 1975, funding was provided by the Air Force for the development of the YJ101 Prototype Engine for use in the Northrop YF17 Air Combat Fighter Aircraft. At the termination of this program, the USAF provided funding for a Continuing Engineering Program to be conducted during FY 1975. This program utilized remaining technical and fiscal resources from the YJ101 Prototype Program to complete a five-element schedule consisting of Engineering Studies, Data Analyses, and Limited Test Support.

In accordance with the contract provisions and other direction provided by the USAF Program Manager, the work was summarized and a formal report prepared in each of the five areas:

TM75AEG1181 - YJ101-YF17 Aircraft Operational Matching

TM75AEG1425 - YJ101-GE-100 Prototype Engine Technology Report

TM75AEG1182 - YJ101-GE-100 Prototype Engine Development

TM75AEG1183 - YJ101-GE-100 Prototype Engine Life - Maintainability

TM75AEG1180 - YJ101 Engine - YF17 Performance Matching

This report presents a summary of the information contained in the above reports and describes in detail the results of each program phase.

LIST OF ILLUSTRATIONS

Figure	Caption	Page
Figure 1	Northrop YF-17 Lightweight Fighter	2
Figure 2	Windmill Start - Engine Standard Day Envelope	9
Figure 3	YJ101-GE-100 PPFRT - Altitude Demonstration Typical Afterburner Light-Off Characteristics	9
Figure 4	J101 Afterburning Turbojet	28
Figure 5	YJ101 Engine Major Components Features	29
Figure 6	YJ101 First Engine to Test (FETT) July 29, 1972	30
Figure 7	6-Hour PPFRT Endurance Test Cycle	31
Figure 8	Engine Installation Arrangement	36
Figure 9	YJ101 Engine Modules	37
Figure 10	YJ101 Engine Structures Component Test Evaluations	38
Figure 11	Aircraft and Engine Operating Envelopes	45
Figure 12	AEDC Test Experience	46
Figure 13	J101-GE-100/F-17 Compatibility "Time Tunnel"	47
Figure 14	Geometric Characteristics of F-17 Model	48
Figure 15	F-17 Model in Wind Tunnel	49

YJ101 - YF17 AIRCRAFT PROTOTYPE

DEVELOPMENT SUMMARY

TABLE OF CONTENTS

1.0 Introduction

2.0 YJ101 - YF17 Aircraft Operational Matching

- 2.1 Reference (TM75AEG1181)
- 2.2 Summary
- 2.3 Conclusion

3.0 YJ101 - GE - 100 Prototype Engine Technology Report

- 3.1 Reference (TM75AEG1425)
- 3.2 Summary
- 3.3 Conclusion

4.0 YJ101 - GE - 100 Prototype Engine Development

- 4.1 Reference (TM75AEG1182)
- 4.2 Summary
- 4.3 Conclusion

5.0 YJ101 - GE - 100 Prototype Engine Life - Maintainability

- 5.1 Reference (TM75AEG1183)
- 5.2 Summary
- 5.3 Conclusion

6.0 YJ101 Engine - YF17 Aircraft Performance Matching

- 6.1 Reference (TM75AEG1180)
- 6.2 Summary
- 6.3 Conclusion

YJ101 ENGINE - YF17 AIRCRAFT

PROTOTYPE DEVELOPMENT SUMMARY

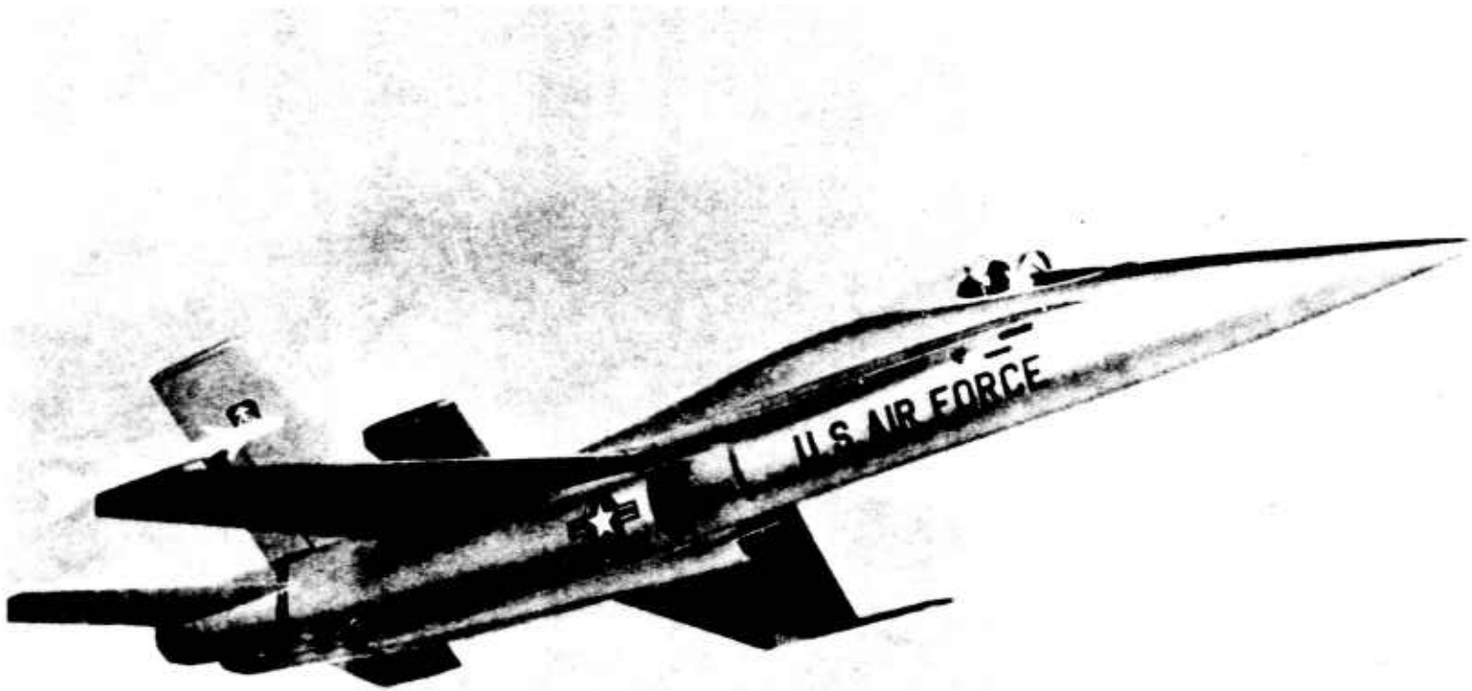
1.0 INTRODUCTION. An extremely successful prototype aircraft flight test program was conducted on the Northrop YF17 Air Combat Fighter Aircraft during the 1974 to early 1975 time period.

This aircraft was powered by two (2) prototype YJ101-GE-100 turbojet engines which were developed under an innovative USAF-GE program concept. The engine program covered the phases of engine design, development, and aircraft flight testing with the main objective being to match the end prototype aircraft flight test program requirements.

The YJ101 Prototype Preliminary Flight Rating Test (PPFRT) engine development program covered the time period from early 1970 through to the successful completion of the YF17 aircraft flight test program in early 1975. During this time a total of 2455 engine test hours were accumulated with 691 engine flight test hours and 288 aircraft flights.

At the completion of the YJ101 Prototype Development Program the USAF provided funding for the Continuing Engineering Program for FY 1975 consisting of design engineering, trade studies, limited test hardware for prototype engine components and program test support. The purpose of the program was to organize and rationalize prototype engine development experience and data into sound technical, programming and fiscal information for the ACF Source Selection and Air Force procurement options, and to investigate the fundamentals of engine development practices in light of Scientific Advisory Board recommendations.

NORTHROP YF-17 LIGHTWEIGHT FIGHTER



TWIN J101 TURBOJET ENGINES

J101-64 (9-72)

Figure 1

2.0 YJ101 ENGINE - YF-17 AIRCRAFT OPERATIONAL MATCHING

2.1 Reference. TM75AEG1181: YJ101 Engine - YF-17 Aircraft Operational Matching.

This report summarizes the engine design approaches, development and flight test results relative to its operational performance and matching to the YF-17 aircraft system needs. More detailed YJ101-GE-100 engine design performance and development program approach information can be found in previously issued reports.

2.2 Summary. The prototype YJ101 engine, designed after extensive performance and matching discussions with the YF-17 air combat fighter manufacturer, emphasized the capability to operate under extreme maneuver requirements providing stall-free engine capability throughout the aircraft operating envelope. Extensive inlet compatibility and performance assessments were conducted (see TM75AEG1180, YJ101 Engine - YF-17 Aircraft Performance Matching). In order to achieve utmost performance effectiveness of the aircraft in the air combat arena, the engine design was optimized to achieve maximum aircraft sustained turn capability, resulting in a high sea level static thrust to take-off goals weight rated.

As part of the coordination of integrating the aircraft inlet design and the engine distortion acceptance capability, Northrop defined fifteen flight conditions as being important to check compatibility, and the five worst distortion requirements were selected to evaluate engine capability. One of the considerations was the impact of idle thrust on ground operation, while other arenas as altitude flight maneuver loads, EMI, and JP 4 fuel were investigated. Selection of a typical aircraft mission allowed the engine design to be established with adequate operational, reliability, and durability capabilities. Some of these operational design characteristics include:

- "Cool skin" engine, reducing heat rejection and aircraft cooling requirements to engine components.
- Engine components and servicing areas positioned for ease of accessibility when installed in the aircraft.
- Engine lube and hydraulic systems which are self-contained and designed for heat rejection capability and operation environments and the altitude of the aircraft.

2.2 - Continued

- o Engine electrical system which is self-contained and designed for Electro-Magnetic Interference (EMI) and susceptibility protection capability.
- o Engine control system designed to meet the air combat fighter engine design operational needs.
- o Engine system design providing customer bleed air and power extraction to meet the aircraft needs.
- o Engine combustor designed for smoke-free operation.
- o Engine components (accessories) designed to be compatible with the air combat fighter installation environment temperatures and "g" loads.

2.2.1 Evaluation Testing Program. An extensive engine and components development testing and evaluation program was conducted to establish engine operational capability prior to flight. During these testing programs, continual assessments were made of the engine operational capabilities. Engine problem areas were reviewed and action plans established relative to the flight test program needs.

In addition to the endurance testing which established and developed parts durability and reliability, other significant operationally significant full engine testing included:

- o Engine performance and transient response.
- o Lube and fuel system performance and heat rejection.
- o Bleed air extraction endurance testing and gas sample analysis.
- o Aircraft inlet duct performance effect.
- o Airframe accessory drive-starter system checkout and vibe survey.

Over 37,000 component test hours were accumulated on the low pressure compressor, high pressure compressor, combustor, engine mechanical parts, controls and accessories, lube system, and electronic components.

2.2.2 Control Operation. The engine control system is a modern integrated electro-hydraulic-mechanical system designed for simplicity, reliability, maintainability, low cost which provides automatic engine operation throughout the flight operating range by means of a single power lever.

2.2.2 - Continued

The control system automatically prevents the engine from exceeding any of its operating limits within the engine operating envelope and provides the optimum relationship between manipulated and controlled engine variables throughout the operating range of the engine. In the event of an electrical failure, the control system is capable of PLA modulation of thrust. For any single control failure, the system is designed to prevent excessive overspeed or excessive overtemperature.

2.2.2.1 Altitude Test Summary. A highly successful test under simulated flight conditions was completed in the fall of 1973 at the USAF Arnold Engineering Development Center. All program objectives were met or exceeded in 102 hours of evaluation testing on the single installation of engine YJ101, S/N 214005-1. The following engine characteristics were evaluated:

- Steady state performance.
- Thrust transients.
- Altitude starting and A/B lightoff.
- Inlet distortion (compatibility).
- A/B stability.
- Control system evaluation.
- Low Pressure Compressor Aeromechanical survey.

Engine operation throughout the test was trouble-free except for non-related problems attributed to the altitude high pressure turbine forward blade retainer seal fatigue failure and a main fuel control P3 sensing system vibration sensitivity problem. Both these problems were corrected and a teardown of Engine 005-1B at the completion of the test showed all hardware was in excellent condition.

2.2.2.2 Engine Steady State Performance. Steady state performance demonstrated during the AEDC test showed that engine operation was excellent throughout the full flight envelope.

2.2.2.3 Engine Transient Performance. Engine transient times generally met spec requirements with no overshoots of either speed or temperature and no evidence of oscillation or other instability.

2.2.2.4 Inlet Distortion (Compatibility). Stall-free inlet compatibility was successfully demonstrated with four (4) engine Model Spec pattern distortion screens. In addition, a fifth "flight type" distortion screen was tested which produced levels of distortion substantially greater than the Spec screen levels. No stalls were encountered except one which was deliberately induced by the fuel pulsing.

2.2.2.5 Windmill Airstarts. Windmill air starts were completed at AEDC. Test conditions are shown in Figure 2.

2.2.2.6 Afterburner Lights. The afterburner lights demonstrated 60 successful afterburner lights throughout the envelope and on the A/B initiation limit line. Test data confirmed that the low bypass ratio and nozzle area scheduling were properly tailored to give soft lights, as demonstrated at AEDC.

2.2.2.7 Overall Engine Operation. The mechanical integrity of the engine components was outstanding during the AEDC test:

- Control and fuel system components were failure-free.
- Self-contained lube system did not require supplemental cooling.
- Engine vibration levels remained within limits.
- Engine components were in excellent condition at the end of the test.

2.2.3 Engine-YF-17 Aircraft Flight Test.

2.2.3.1 Flight Test Summary. Operation and performance of the YJ101-GE-100 engines during flight testing met or exceeded the expectations for a prototype engine. Results demonstrate that the YJ101 engine has been successfully designed to match the unique and advanced capability of the YF-17 Air Combat Fighter. Among significant results were:

- No engine stalls.
- Successful augmentor lightoff and operation.
- Successful windmill airstarts.
- Periodic engine inspections completed as scheduled with excellent results.
- All engines returned to flight status.

2.2.3.2 Engine Flight Envelopes. The YJ101 engine successfully operated over a large portion of the flight envelope and in some areas, outside the envelope.

2.2.3.3 Windmill Air Starts. Successful air starts with normal aircraft power extraction were made outside the left side of the envelope expanding the capability demonstrated at AEDC with no power extraction.

2.2.3.4 Augmentor Lightoff. Only one A/B light was unsuccessful. The A/B fuel flow schedule was changed and augmentor operation proved to be excellent with fully automatic light-offs and smooth operational transitions from mix to mix.

2.2.3.5 Aircraft/Engine Transients. Stall-free operation was experienced at conditions more severe than original predictions.

2.2.4 Operational Incidents. During the flight program some engine-related operational problem areas were identified that required immediate corrective actions while others were acceptable "as is" for the prototype flight test program. All corrective actions taken were successful in allowing completion of the flight test program objectives.

2.2.5 Special Operational Investigations. During the flight test program several special operational test evaluations were conducted in regard to the following:

- o Engine augmentor modifications.
- o Special trimming of the engines for faster thrust transient acceleration.
- o Special trimming of engines to reduce ground idle speed.

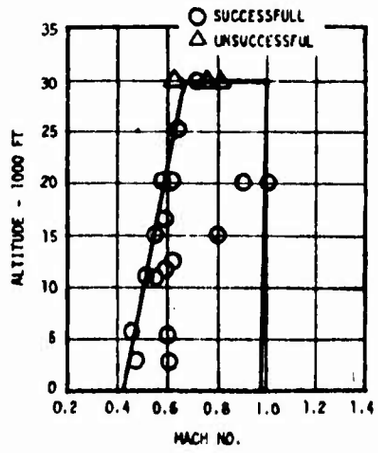
2.3 Conclusions.

- o The prototype YJ101-GE-100 engine successfully provided operational capabilities required for the YF-17 aircraft flight test program.
- o The engine operational capability met all necessary requirements to enable full demonstration of the prototype YF-17 aircraft fly-off capability.
- o Engine operational capability and improvements implemented during the flight test program demonstrated the prototype YF-17 aircraft improved capabilities and projected future F-17 air combat fighter potential.

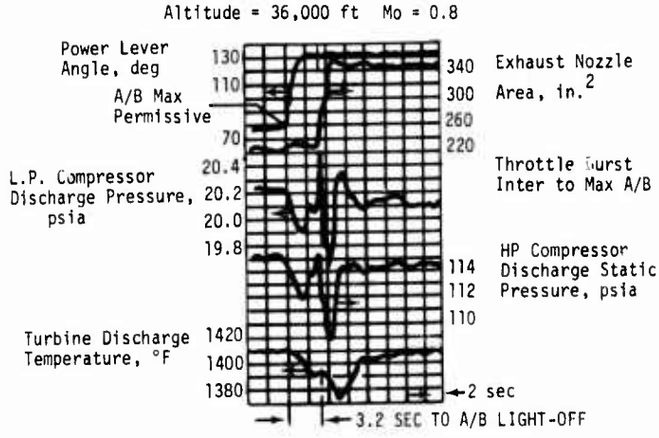
2.3 - Conclusions

- The engine development program provided an effective engine evaluation and demonstrated an operational capability to confidently initiate the prototype aircraft flight test program.

- Engine altitude testing at the USAF AEDC facility was significant in demonstrating operational capabilities required for the YF-17 aircraft flight test program.



WINDMILL START
ENGINE STANDARD DAY
Figure 2



YJ101-GE-100 PPFRT - ALTITUDE DEMONSTRATION
TYPICAL AFTERBURNER LIGHT-OFF CHARACTERISTICS
Figure 3

3.0 YJ101-GE-100 PROTOTYPE ENGINE TECHNOLOGY REPORT

3.1 Reference. TM75AEG1425: YJ101-GE-100 Prototype Engine Technology Report (U).

This report describes in detail component testing conducted under the YJ101 Continuing Engineering Program.

3.2 Summary. This portion of the YJ101 Continuing Engineering Program was directed toward completing engineering studies and limited engine/component testing in order to resolve the technical status of selected components in the prototype engine. Some advanced technology components were incorporated into the YJ101 engine design. Primary emphasis in YJ101 component prototype development was to achieve safe flight and deliver performance with respect to schedule and cost. Since technical resolution of several components had not been completed, a program was conducted to resolve the technical/cost aspects of these components. A summary of these studies and tests follows.

3.2.1 Low Pressure Compressor. An advanced technology, high tip speed, 3-stage low pressure compressor developed for the YJ101 engine features a nearly cylindrical outer flowpath. This flowpath, which maintains high tip speed in the second and third stages, produces a very high pressure ratio per stage which averages 1.57. The aerodynamic design combines both high performance and superior distortion handling characteristics. The objective under the Continuing Engineering Contract was to investigate the differences in performance between the component and the engine through controlled and systematic testing on YJ101 Engine 102 - a flight test engine which had flown in the YF-17 Flight Test Program. A review of the PPFRT blading quality was also conducted. The program on Engine 102 included:

- Mapping the LPC performance from 75 to 105% N and from 3% below the standard operating line to 12% above.
- Testing with the first stage rotor blades from the component test to assess the shroud and quality effects.
- Testing with first stage rotor blades reworked to improve quality.
- The effects of off schedule IGV and Stator 1.

3.1 - Conclusions

In LPC component tests conducted in 1971 and 1972, performance exceeded design speed airflow, and met or exceeded the efficiency, stall margin, distortion sensitivity and distortion transfer goals. Changes to the stage 1 blade to improve the mechanical integrity and torsional stability degraded the overall LPC efficiency more than anticipated at design speed.

The test program is described in detail in the referenced report, and the results of each of the phases of the testing is provided.

Retesting of the PFRT blading provided higher efficiencies than the previous status and consistent to higher airflows believed due to a more controlled systematic test.

Retesting with the component first stage rotor blades showed efficiency increases up to 1.1 points at high corrected speeds and small decreases (-0.3 points) at part speed relative to the PPFRT rotor Stage 1 blades. This gain must be attributed to the part span shroud differences. However, the engine level efficiency was still 1.0-1.5 points below that of the component test.

Testing conducted with more open IGV schedules and then with more closed stator 1 schedules indicated a different response to these variations between the engine and the component test. These different responses as well as the efficiency difference noted above could indicate a difference in stage matching.

Airfoil profile quality characteristics of the PPFRT blade were found to be less than required and inferior to that of the component test. However, reworking the PPFRT blades for improved profile conformance did not improve peformance.

3.2.2 High Pressure Compressor. The High Pressure Compressor of the YJ101 engine is an advanced technology, seven-stage design of low aspect ratio blading and with a high pressure ratio per stage. It has a cylindrical hub and tapered tip flowpath to provide high loading within reasonable rim speeds. Development under the PPFRT program showed good performance and distortion tolerance but analysis of the data indicated the potential for further improvements. Specific modifications required were axial rematching, increased throat margin in rotors 1-3, and reduced clearances. An "Improved Compressor" was laid out in which rotors 1-3 were restaggered open 1 degree with an accompanying reduction in solidity of 12% on rotors 1 and 2 and 6% on rotor 3. Stators 3, 4 and 5 were restaggered closed and the camber was increased on stators 4, 5 and 6. The clearances relative to PPFRT levels were decreased.

3.2.2 - Continued

The test program consisted of:

- o VG optimization.
- o Clean inlet mapping to stall.
- o Complex inlet distortion.
- o Tip radial distortion.

The stall line of the Improved Compressor was higher at all speeds. Adiabatic efficiency improvements ranged from 1.6 points at part speed to 0.7 points at high speed.

Interstage wall static pressures and pitchline temperatures were measured and individual stage performance reported. Characterisitics and results are given in the referenced report. The Compressor Axisymmetric Flow Determination computer program (CAFD) was used to establish the entire three dimensional flow field. For this testing, data matches were done for clean inlet and tip radial distoriton test points. Studies were conducted using this data which led to redefintion of the tip radial match on the IGV and Stator 1 and 2.

3.2.3 High Pressure Turbine. A cooled air turbine test of the redesigned J101 High Pressure Turbine was conducted in late 1975, to determine the performance of the turbine in a realistic simulation of engine environment including cooling and leakage flows. Design point efficiencies were measured using exit total pressures determined by (1) rakes and (2) circumferential traverses and two different values were obtained. Although both values were improvements over the original J101 engine HPT, intense investigation was pursued to reconcile the discrepancy.

The effect of blade tip clearance on efficiency was found to be less than expected or assumed in previous analysis. Exit swirl was well below the design value.

The total performance improvement of this turbine over its engine version was less than expected. Data analysis was continued.

3.2.4 Low Pressure Turbine. Cascade and warm air turbine tests were conducted on the original and modified versions of the complete J101 low pressure turbine, and on the turbine nozzle alone, over a twelve month period starting in August 1974. Purpose of these tests was to establish the aerodynamic performance of the turbine and nozzle, to investigate the effect of various nozzle modifications on nozzle cascade efficiency, and to select from the modified nozzles tested a design which in combination with the existing buckets would achieve a turbine design point efficiency 2.8 points better than the efficiency established from engine operating data. The primary loss area in the nozzle occurred in the 5-25 and 70-90% span region and was associated with endwall secondary flow and/or endwall separation losses. Even with low nozzle performance the basic turbine aerodynamic performance was .2 points above the design objective. The turbine with redesigned nozzle did not show the expected efficiency improvement achieving design point efficiency. Tests conducted on the turbines to determine the effects of changes in rotor clearance, airfoil cooling flow levels,and turbine Reynolds Numbers on efficiency gave no big surprises although the Reynolds Number effects were somewhat higher than expected.

3.2.5 Augmentor. Flameholder durability was significantly improved by reshaping the vane trailing edges to provide more uniform cooling flow. The addition of a ramp to each vane improved airflow characteristics with no loss in afterburner efficiency.

A "chute-mixer" was tested to assess the effects of mixing bypass air with core engine airflow at the inlet to the afterburner. This design permitted burning of a portion of the bypass airflow not required for liner cooling. Testing showed that a resulting improvement in fuel/air distribution was offset by an efficiency loss due to incomplete combustion. It is expected that a spraybar redesign would improve combustion and produce a higher component efficiency.

3.2.6 Bowed Rotor. Numbers 1 and 3 squeeze film bearings were proposed to dampen engine vibrations due to bowed rotor starts. The number 1 squeeze film bearing installed alone had little effect on the engine vibration condition. When the number 3 squeeze film bearing was installed with the number 1 engine vibrations were reduced to an acceptable level. The capability of the squeeze film number 3 bearing by itself has yet to be evaluated.

3.3 Conclusions.

- Data obtained on the LPC from engine 214102 formed the basis for a new "status" performance representation that is 1/4 to 1/2 point higher efficiency at high speed and 1-1/2 points higher at part speed than previous representation.

- Aerodynamic modifications to the PPFRT compressor improved the adiabatic efficiency and improved stall margin with no change in distortion sensitivity.

- Continued effort is required to understand the differences in the HP turbine efficiencies and the reasons for the less than expected improvement.

- The expected LPT efficiency improvement has been achieved and is suitable for the desired J101 design.

- The durability objectives of the augmentor program were met. Further work with spraybar redesign is expected to yield the needed efficiency improvement.

- The number 3 squeeze film bearing has potential for fixing the bowed rotor start problem, but additional testing is required.

4.0 YJ101-GE-100 PROTOTYPE ENGINE DEVELOPMENT

4.1 Reference. TM75AEG1182: YJ101-GE-100 Prototype Engine Development.

This report covers the overall YJ101 prototype engine development programming aspects from its initiation through the prototype aircraft flight test program. Significant positions, trade-offs and activities that influenced the program content and success are presented. This report does not present the technical data related to the engine designs and performance, as this information has been presented in YJ101-GE-100 Engine Design Report R73AEG11-1 and YJ101 Engine - YF17 Aircraft Performance Matching Report TM75AEG1180.

4.2 Summary. This aspect of the program was directed toward studies to establish the needs and approaches utilized in relating YJ101 engine design and development, development testing, and subsequently flight testing. These studies established comparative data and information between program technical approaches and subsequent results/data in the areas of technical projections, design refinements/trade-offs, and cost factors.

The unique USAF Program Management Concept placed responsibility on the engine aircraft contractors to define, implement, and conduct successful aircraft flight test demonstration. This concept resulted in the definition of an Engine Prototype Preliminary Flight Rating Test Program which emphasized teamwork between the USAF and the engine/airframe contractors in the definition of the Engine Model Spec. E1197. The team approach on rapid, informal communication, decision-making and action implementaion was a significant factor in the successful accomplishments on this program.

The program evolved through extensive design concept matching with the airframer for performance and operational capability. This effort concentrated on providing a low cost and lightweight system for the aircraft and many tradeoff assessments were made as the result. Significant prototype program objectives accomplished are:

Program Initiated	1970
Core Engine to Test	3/72
First Engine to Test	7/72
Mock-up Engine Shipped	7/72
Altitude Test Engine Shipped	6/73
Prototype PFRT Complete	12/73
First Flight Engine Shipped	12/73
First Aircraft Flight	6/74
691 Hours of Flight Testing Complete	2/75

4.2 - Continued

The engine design objective for the demonstrator was based upon requirements established for a lightweight, low cost turbojet fighter engine. The approach was to set component performance cycle levels as high as practical using demonstrated, advanced, low risk/cost components. These components were to be designed using established and extended technology where required and evaluated on core or full engines with a minimum of prior component testing. These objectives were continually monitored by the responsible design groups throughout the development program to assure that the overall engine performance requirements were met. Design reviews with other AEG engine design groups, and with the Chief Engineer's office were of significant benefit in assuring use of the latest design practices and avoiding problem areas on other engines. Consultation with Value Process Engineering enabled development of low cost engine parts drawings prior to drawing issuance. Simultaneously weight was calculated by the design engineers so as to make best possible cost/weight trade-offs. Another aspect of the engine design was the evolution of the design consistent with the airframer requirements through continual communication and consultation. Engine parts were designed both to meet the requirements of Engine Model Spec E1197 and requirements for the aircraft mission usage and life.

Engine components were designed to withstand operating conditions represented by the composite mission and included consideration for the following mechanisms:

- o LCF - 5000 cycles
- o HCF
- o Creep
- o Stress Rupture
- o Thermal Fatigue

Design life will not include consideration for:

- o Assembly/Disassembly Damage
- o Repairable Wear
- o Abnormal Overspeed and Overtemperature
- o Foreign Object Damage
- o Excessive Erosion
- o Expendable Items

4.2.1 Low Pressure Compressor. The low pressure compressor is an advanced three-stage component with a 3.9:1 pressure ratio and 1540 ft./sec. tip speed. Since there was no existing component to scale which fit the unique needs of an advanced fighter engine, selection of this design did add risk to the low budget prototype program. Some key features which contributed to successful operational characteristics were:

- o High blade tip which allowed three stages to do a job normally requiring four.
- o High rotating speed which made a single stage low pressure turbine possible.
- o Low aspect ratio, high solidity blading to reduce distortion sensitivity, increase stall margin and enhance distortion attenuation.

The success of the low pressure compressor turned out to be a key to the outstanding success of the YJ101 Program.

Significant program approaches taken to insure a successful prototype program were:

- o Full scale component testing was conducted in early 1972 where the Low Pressure Compressor (LPC) was run for the first time as a component.
- o Full engine low pressure compressor inlet distortion testing with blade and vane strain gages was conducted on altitude test engine 214005-1 at AEDC.

4.2.2 High Pressure Compressor. The 7-stage YJ101 Compressor is an .88 linear scale of stages 2 through 8 of the USAF/GE F101 engine. This approach was ideal for a low cost prototype development program as the F101 offered a proven base to work from. The F101 compressor had been developed to the point where good performance, stall margin and distortion tolerance would be expected.

Significant design features included:

- o Bolted IN718 disks substituted for the F101's inertia welded R95 aft spool.
- o Casing loads were sprayed with nickel graphite eliminating need for casing sub liners.
- o Stages 1 and 2 of the compressor rotor were modified to have the same number of blades.

4.2.2 - Continued

One of the most significant approaches to the low cost prototype engine development program was the use of a core engine rather than a component test/rig facility to develop the high pressure compressor. Distortion tests and aeromechanical tests were run.

4.2.3 Combustor. Comprehensive aero-thermodynamic modeling techniques produced an advanced, low-cost, lightweight combustion system by scaling the successful CF6/F103 engine design. The resultant YJ101 combustion system successfully met the PPFRT engine performance requirements with only two trim modifications which were developed on the component stand test program. It is significant that this combustor showed an excellent engine test turbine temperature profile. There were no incidents of highly localized hot spots throughout the engine development test program.

Significant design features include:

- o Step Diffuser
- o Medium pressure fuel injection
- o Common to CF6 engine dual orifice fuel nozzles
- o Sheetmetal stocked ring liner

Significant program approaches taken to assure a successful prototype program were:

- o Early full scale combustor testing
- o Commonality of design approach with the CF6
- o All engine combustors tested prior to engine assembly

During the engine development test program the combustor showed excellent performance and mechanical results.

4.2.4 High and Low Pressure Turbines. The YJ101 high pressure and low pressure Turbines were designed as single stage turbines based on initial cost, weight and performance trade-off studies. F101 engine technology was utilized in the selection of materials and cooling system configurations.

4.2.4 - Continued

Both turbines were initially designed for full life capability.

Significant design features included:

- o Single state HP and LP for low engine cost/weight.
- o Incorporation of cooling system accelerator to minimize use of cycle chargeable cooling flow.
- o Use of existing dovetail forms from other G.E. engines.

During the engine development program several problems were encountered which required design engineering corrective action. Several solutions were defined and accepted on the basis of being adequate for the prototype flight test program with specific "hot section" inspection intervals and acceptability limits.

4.2.5 Afterburner - Variable Exhaust Nozzle. The afterburner for the YJ101 engine was defined and developed in three phases. The initial phase was the design and testing of the J1A1 afterburner on the J97 engine in the 1968-69 time period. The second phase was further testing of the J1A1 afterburner on a component test stand in the 1970-71 time period. The third phase was the YJ101 afterburner design and testing both in the factory and on the YF17 aircraft flight test program.

The YJ101 design concept was evolved from J1A1 afterburner (two thirds the size of the final YJ101) and proven features from other GE engines and advanced engine developments.

Significant design features included:

- o Low pressure compressor bypass air providing a cool film for the A/B casing and exhaust nozzle
- o Self-supporting liner
- o Annular pilot "flow-thin" flameholder
- o Two stage system fuel system
- o Eight (8) sets of primary flaps and seals
- o Lightweight titanium roller support frame and actuator ring
- o Eight (8) sets of secondary (outer) flaps and seals which form the boattail surface of the aircraft

4.2.5 - Continued

During engine development and flight test programs some problems were encountered which required design engineering corrective action. Again, the prototype program concept and the USAF-Northrop-General Electric team approach were able to implement acceptable design modifications with rapid timing and minimum program complexity and disruption.

4.2.6 Structures - Configuration Design. The YJ101 engine structures were designed for their useful life based upon the F-17 aircraft power management analysis, material properties, inspection limits and experimental and analytical stress analysis.

Significant design features follow:

- o Simplified three (3) frames engine support structure
- o Front frame furnace brazed 410SS design
- o Diffusion bonded titanium honeycomb sandwich outer duct.

4.2.7 Lube System. The YJ101 engine lubrication system stresses simplicity, safety and low cost, and where possible uses commonality of parts.

Significant design features include:

- o Simplified system of only 5 main rotor bearings and 3 sumps for the two (2) engine rotor systems.
- o Self-contained engine lube system with a simple oil fill port and "dip stick" for oil level determination.
- o Twenty (20) micron nominal oil filtration at the lube pump discharge to oil jets.
- o Unique swirl chamber and eductor system in oil tank.

Past General Electric experience and the lube system design program enabled definition of a component and simulated engine lube test vehicle (LTV) testing program to be conducted in conjunction with the engine test program. This LTV testing capability proved to be a "payoff" in the resolution of engine testing problems.

4.2.8 Gear Design. The well integrated engine airframe design matching efforts produced several significant unique gear system design concepts. These concepts and conscientious application of past gear design experience and low cost/weight designing were utilized in establishing the final gear system designs.

Significant design features include:

- o Single airframer shaft
- o AGB bearings of 52100 material
- o Magnesium AGB casings
- o Rotor mounted horizontal bevel gear

A 60-hour gear system component load stand test was considered necessary to provide assurance of maximum engine and aircraft power extraction requirements.

4.2.9 Controls/Accessories. The latest General Electric technology in controlling operation of two rotor system bypassing afterburner engines coupled with the years of engine control design experience was assessed in the selection of the YJ101 engine parameters requiring control and establishing of the baseline control system. Numerous trade studies were performed in various areas of the control system in order to select methods of mechanizing the various required functions and to optimize cost, and weight, and yet meet performance, reliability and failure mode requirements unique to this engine.

Main Fuel Control - $T_{2.5}$ Sensor. One of the basic engine requirements largely defining the MFC requirements was that the engine operate and generate thrust in cases of electrical power failures. Consequently, the speed governing, acceleration and deceleration and HPVG schedules were performed hydromechanically. A gas filled T2.5 sensor was chosen because of its fast response and compatibility with the hydromechanical MFC.

Variable Exhaust Nozzle Actuation System. To assure high reliability of the fluid supply system, a self-contained hydraulic fluid system was chosen over a system integral with the engine lube oil. The hydraulic power unit contains an integral pump and fluid reservoir. The VEN actuation system design used on the YJ101 engine provides for a simple tracking method of self-synchronization and eliminates the need for rotary cables and gearing.

4.2.9 - Continued

Afterburner Control System. Control system logic functions are performed electrically since they are most easily accomplished by this method. Particularly important in an afterburning bypass engine is the logic and method of controlling A/B flow so as to preserve low pressure compressor stall margin. The A/B fuel control method is unique since the A/B fuel flow is scheduled as a function of actual A_8 feedback position plus the T_6 trim signal.

Afterburner Pump. A vapor core afterburner fuel pump was selected because of the need for a turndown ratio of 85 to 1. A trade study was conducted to determine if downstream or upstream controlling of the vapor core pump was most effective. Results indicated that the control loop tended to oscillate under some flow conditions with the downstream method. The upstream method was stable over the complete operating range and was selected.

Main Fuel Pump. After several pumping systems were studied, it was decided to select a system incorporating three pumping elements on a single shaft (a total flow inlet inducer feeding, a high pressure total flow impeller and a fixed displacement high pressure vane element.)

Electrical Controlling System - Electrical Control. Electrical mechanization was chosen for scheduling T_6, N_1, W_{f_r}/P_3 and LPVG, since they are all functions of T_2 and lend themselves to electrical computation.

Ignition. Trade-off studies were conducted to minimize engine cost/weight and complexity risk. The system design selected was completely engine controlled with airframe override circuits that can be used if desired.

Low Pressure Rotor Speed Sensor (N_1 Sensor). A trade-off study was conducted on the merits of a variable reluctance vs. eddy current N_1 speed sensor. The eddy current sensor, providing the capability of sensing the passing frequency of non-magnetic blades, was chosen to be used at the low pressure stage one blade location.

Other. In the interest of low cost and weight various other trade studies were performed (Duct Mach Number vs. T_6 control of A_8, Isochronous vs. proportional port speed control, and T_{4B} pyrometer vs. T_6 thermocouples).

4.2.9 - Continued

Program Approach and Significant Activities. Some of the innovative program approaches which contributed to a successful engine development program included:

- o A number of component tests to assure designs meeting design specifications.
- o Bench testing of all control system components as single components.
- o Computer modeling and failure mode analyses throughout design and engine development phases.
- o Control system designs subjected to failure mode analysis.

Control Operation

The engine control system is a modern integrated electro-hydraulic-mechanical system designed for simplicity, reliability, maintainability, and low cost. It provides automatic engine operation throughout the flight operating range by means of a single power lever. The control system has two operating modes and automatically prevents the engine from exceeding any of its operating limits within the engine operating envelope and provides the optimum relationship between manipulated and controlled engine variables throughout the operating range of the engine.

4.2.10 Engine - Aircraft Installation Compatibility. In order to assure a compatible engine to airframe installation, early coordination was initiated with Northrop Aircraft personnel. Engine to aircraft interfacing layout design studies, installation drawing, an Interface Control Document (ICD) utilized to control the airframe and engine physical and functional interfaces) and engine mockups were utilized in defining engine configuration requirements. The J101 engine external configuration was designed to satisfy the envelope requirements of the YF17 airframe power plant bay. The strongly airframe installation integrated engine design approach resulted in engine configurations of specific benefit to the airframer.

During the engine testing program, the following aircraft related tests were successfully conducted.

- o Inlet Distortion
- o Northrop full scale mockup inlet duct tested in front of engine prior to first flight.
- o Northrop aircraft accessory gearbox system check out on engine in cell prior to first engine aircraft installation.

4.2.11 Development Evaluation.

Program Approach

Initial component and engine development test plans were modified as the engine program changed from an engine demonstrator program to the prototype YF17 aircraft flight test program. Several engine test program trade-offs were made to define a low cost, timely, and acceptable plan using a GE developed computer program. A significant factor in the success and low cost of the program was participation by design and evaluation engineers in the engine hardware, engine assembly/inspection and testing phases on all development and flight test engine builds.

Engine Test Program

The engine test program was designed and conducted to provide assurance that the engine would pass the MIL Spec 5009 endurance test required by the E1197 Engine Model Specification. Performance and durability limitations were resolved mutually with the USAF and GE and the experience was made part of the engine maintenance plan.

Development Testing Summary

Significant accomplishments achieved during the YJ101 prototype engine development program include:

- o Fixes for engine deficiencies requiring corrective action prior to PFRT.
- o Demonstration of engine system capabilities at sea level static and altitude ram conditions.
- o Demonstrated satisfactory compressor aeromechanical characterisitcs at sea level static and altitude ram conditions.
- o Completion of official tests and demonstrations per specification/contract requirements.
- o Engine completed PPFRT Endurance Test.

4.2.12 Flight Test Program. A total of seven (7) prototype engines supported the two dual engine prototype aircraft intensive flight test program where a total of 288 flights were completed in the 32-week time period. Operation and performance of the engines met or exceeded the expectations for a prototype engine.

4.2.12 - Continued

Engine Maintenance

Full use was made of factory engine experience throughout the YJ101 engine flight test program. The maintenance concept for the flight engines was developed with USAF participation based on the condition of hardware after engine endurance tests and engine 005 after 102 hours of altitude operation at AEDC. Results of engine inspections during the flight program showed that the maintenance plan was sound for this prototype program.

Lynn Engineering Flight Test Program Support

Lynn Engineering support of the flight test resulted in rapid and effective fixes for engine problems. Direct daily contact between the Edwards stationed field reps and Lynn Engineering Management was an important factor in fast problem recognition and resolution.

All facets of each flight were reviewed and any incident or event was investigated and followed through to resolution. Strong emphasis was placed on the procurement and analysis of data from each phase in the flight test so that engine performance and operation were known at all times.

Field Service Engineering Rep Support

The experience of resident General Electric engineers providing around-the-clock on-site customer support, was a vital factor in the support of flight engines. They monitored displayed telemetered data during every flight, attended post-flight briefings, and transmitted this data to Lynn Engineering daily for information and action.

General Electric - Edwards Support

The extensive and diverse background of General Electric - Edwards personnel providing on-site maintenance and test support put GE - Edwards Flight Test Center in a unique position to support the YF-17 program. The facility provided a complete engine shop capability with AGE level equipment, test stands for measuring engine performance and mechanical data, a data acquisition and reduction center and an instrumentation lab, as well as fully equipped machine and metal fabrication shops to support required engine modifications.

4.2.13 Engine Configuration Management. Using the existing successful AEG configuration management procedures and simplifying it for a prototype reduced scope program, a more expeditious, lower cost processing of design releases and changes, as well as, more timely manufacturing implementation was utilized.

4.2.13 - Continued

The most significant change was to provide/use CID's immediately at the manufacturing sources rather than require issued drawings with CID revisions. A more formal control configuration management program was implemented upon completion of the official prototype preliminary flight rating test (PPFRT).

4.2.14 Engine Weight Control. An engine weight objective was established and a weight limit was assigned to each component section of the engine. As actual engine hardware became available, physical part-by-part weights were used to re-assess the actual engine status. A rotor system problem required new design and heavier weight. Rather than undertake a high cost, risk and time extension to hold to the original weight limit, mutual agreement resulted in a redefined weight limit. All shipment engines were well within these limits.

4.2.15 Cost Control. The initial requirement for engine design was to provide a low cost lightweight engine. To assure implementation of cost control, Value Engineering review and signoff of all drawings before issuance was required. A cost limit was established for each part which required joint Design-Manufacturing efforts to present the best possible low cost design. As a by-product of the cost conscious design effort, some innovative approaches resulting in defining lower cost parts were established.

4.2.16 Hardware Control - Procurement. At the initiation of the engine program, a Manufacturing group was established to work as a team with the Design Engineering group in providing hardware costing, procurement and scheduling. The Manufacturing group utilized existing AEG procedures and experienced personnel from past development programs to effectively place parts orders and expedite deliveries.

Organization within Manufacturing included practical groupings of hardware responsibilities for common Vendor/Supplier dealing, as well as, engine parts costing analysis and participation on the Configuration Control Board (CID's). Significant approaches consistent with the limited program scope were soft tooling, single source vendors, common storage pool for parts, and minimum spare parts. Management control included weekly meetings to assure timely delivery of parts for the required engine builds, continual communication of needs with Manufacturing and resolution of mutual Engineering -- Manufacturing problem areas.

A significant contribution to the success of the engine's operation was the detailed part reviews conducted by responsible engineers at each engine build.

4.2.17 Effectiveness Assessment. The prototype program concept conducted on the YJ101 engine was extremely successful with the engine meeting or exceeding all requirements for YF17 prototype aircraft flight test program. The end result has provided the USAF with an excellent, low cost, lightweight turbojet engine with a low program expenditure.

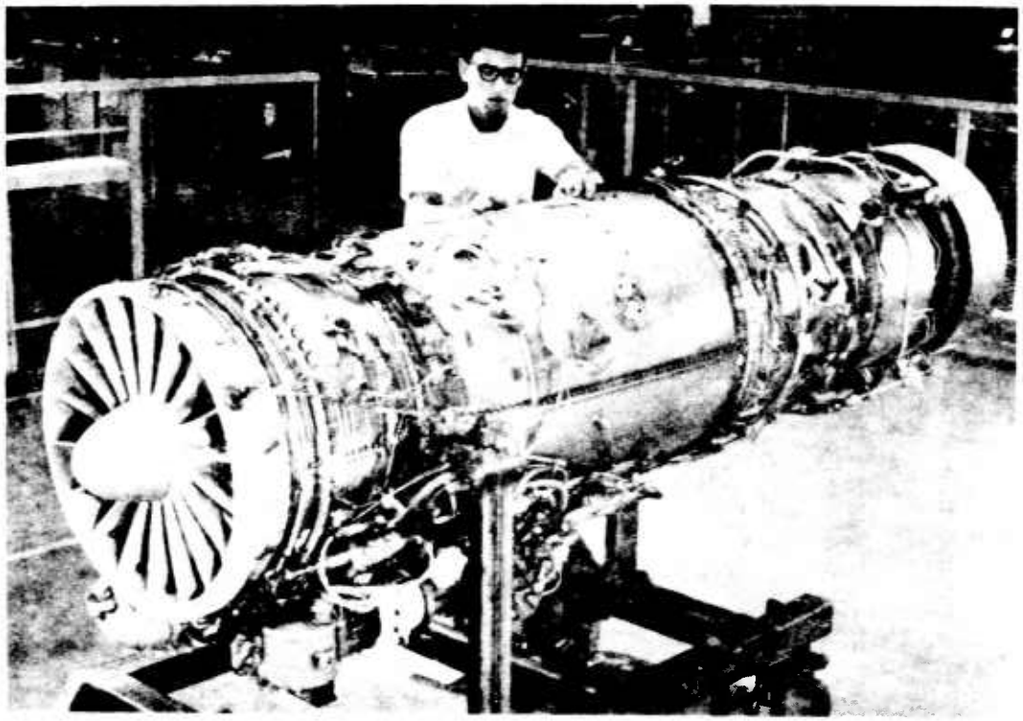
This program concept allowed informal, yet disciplined program management that allowed timely, positive, acceptable solutions to identified problem areas. The recognition by both the airframer and engine manufacturers that they were responsible for the outcome of a competitive fly-off served to spur both to apply maximum efforts to assure program best efforts.

The know-how, engine development experience and selected approaches taken on this prototype engine development program proved to be outstanding as evidenced by the successful results. This was demonstrated by the ability to make consistently successful fast turnaround, first time fixes. In addition the sound, well-derived engine design concepts and approaches provided an excellent solid base engine. A factor in achieving this base was the time allowed earlier in the program to make sufficient trade studies and sound engine design concepts prior to initiating detail engine designs.

The test program conducted showed it provided an effective mix between component and engine test to meet the needs of the prototype flight test program. The base program provided adequate testing time and samples to identify the major problem areas, all of which were resolved by corrective action fixes or defined maintenance actions.

- The prototype engine development program approach applied on the YJ101-GE-100 turbojet engine was extremely effective as demonstrated by the successful YF17 aircraft flight test program.
- The YJ101 engine has demonstrated excellent operational performance at a low development program cost.
- The engine and the program conducted met or exceeded requirements for the flight testing of the YF17 aircraft.
- The mix of component, engine and engine altitude tests were well selected for the required development of this engine and its flight test program.

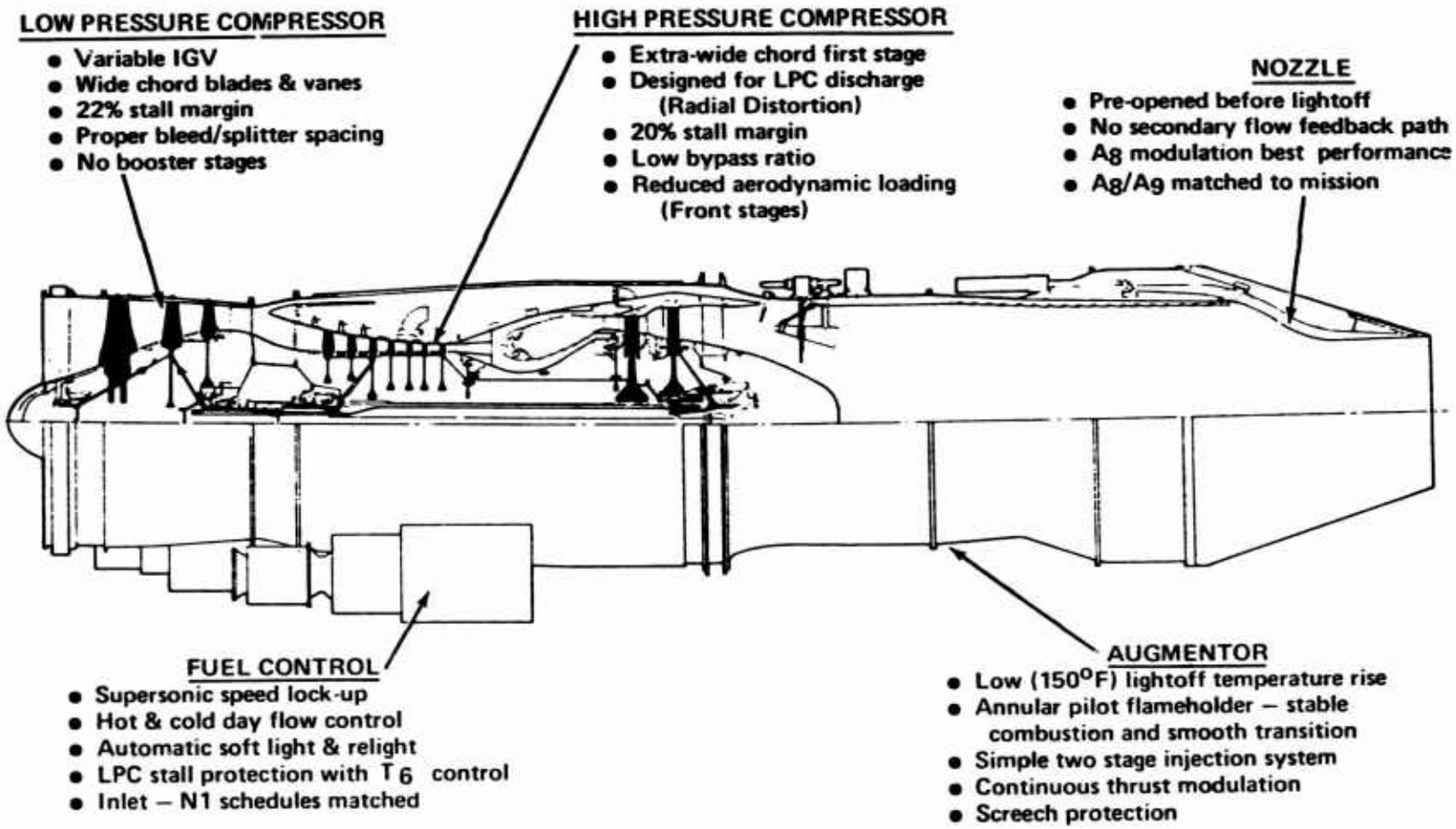
J101 AFTERBURNING TURBOJET



Thrust Class . . .	**15,000 Lbs.**	**Inlet Diameter . .**	**27 In.**
Weight	**1,870 Lbs.**	**Length . . . .**	**145 In.**

J101 133 (2-74)

Figure 4



YJ101 ENGINE MAJOR COMPONENTS FEATURES

Figure 5

YJ101 FIRST ENGINE TO TEST (FETT)
July 29, 1972

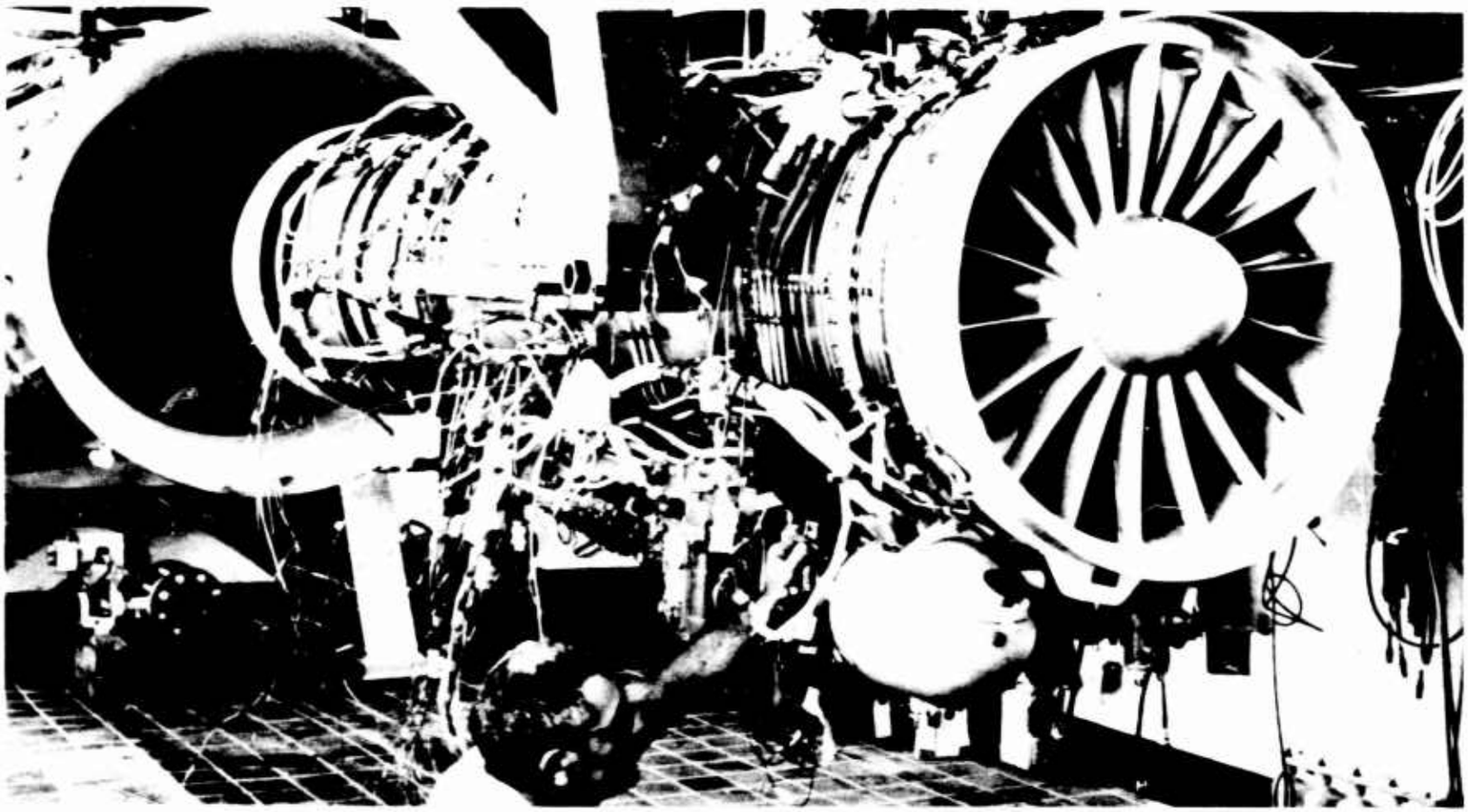
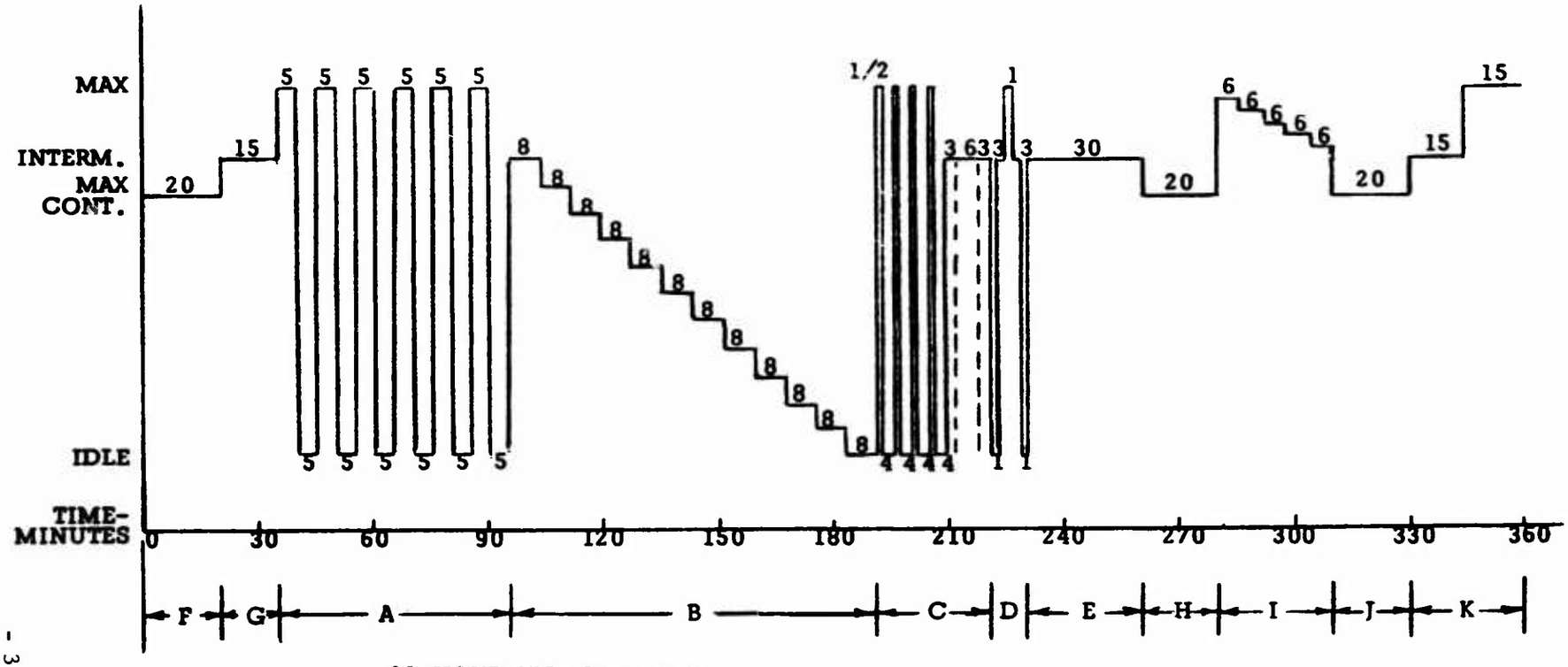


Figure 6



60-HOUR TEST SUMMARY

TOTAL NO. OF SIX (6) HOUR CYCLES		- 10
TOTAL NO. OF CYCLES @ TABLE IIA RATING		- 2
TOTAL NO. OF CYCLES WITH CUSTOMER BLEED		- 2
ENDURANCE TIME		60:00 HOURS
TIME ≥ TABLE II - T MAX		21:52 HOURS
TIME ≥ TABLE II-A - T MAX		5:28 HOURS
AFTERBURNER TIME		13:00 HOURS
TOTAL STARTS		25
- 2 HOUR COOLING	10	
- RESTARTS	5	
- FALSE STARTS	5	
THERMAL CYCLES		160

NOTES:

- T_4 @ TABLE II ENDURANCE: 2445° $^{+10^{\circ}}_{-0}$ F
- T_4 @ TABLE IIA ENDURANCE: 2465° $^{+10^{\circ}}_{-0}$ F

6-HOUR PPFRT ENDURANCE TEST CYCLE

Figure 7

5.0 YJ101-GE-100 PROTOTYPE ENGINE LIFE - MAINTAINABILITY

5.1 Reference. TM75AEG1183: YJ101-GE-100 Prototype Engine Life Maintainability

This report presents aircraft engine life-maintenance methodology and the progression of this concept through design, development and operational phases. Examples of the YJ101 engine design objectives and the prototype development program/results are utilized to illustrate typical and unique approaches taken for fighter engine life and maintainability.

5.2. Summary. This portion of the YJ101 Continuing Engineering Program consisted of studies, predictions, analyses and testing to enhance technical approaches needed to program engine life functions for flight utilization and maintenance. The practical extent to which "engine maximum operating time" (or time between overhauls) can be extended is an essential element in developing improved engine structures/life approaches and methods.

5.2.1 Engine Life-Maintainability Design. The first step in the initiation of an aircraft engine design is the establishment of basic engine requirements. Although methodology is the same for all engines, specific approaches for engine life-maintainability will differ for a fighter aircraft engine as compared to a reconnaisance, commercial airliner or bomber aircraft engine. Engine requirements to a specific aircraft are evolved and established through reviews and negotiation with the Using Service(s), airframer(s) and engine manufacturer and documented in the engine model specification, contracts and engine-airframer interface control documents.

As the basic design concept is evolved, more detailed design and analysis is initiated on engine life, reliability and maintainability aspects. The high performance, lightweight advanced fighter engine will typically have a lower time inspection/overhaul interval due to its higher demand, more severe usage effects (higher speeds/temperatures and transients) on parts durability/life. Also, the slower buildup of fighter engine usage hours over calendar year periods results in setting lower ultimate total engine usage lives (i.e., 4,000 versus 10,000 hours).

Based on the overall engine life and maintenance objectives, each of the engine parts have a defined life requirement. For the YJ101 engine a design life objective of 3,600 hours was defined. Continual assessment of part lives and their requirements are necessary throughout an engine development program.

5.2.1 - Continued

True maintainability is achieved through design attention to individual parts' lives. The ability to remove or inspect life limited parts, with minimal impact on availability and costs is essential.

In order to increase the installed or "on base" engine life, engine maintenance modules are defined and designed. This enables replacement of life-limiting parts(s)/component(s) more easily by installing another part of the module, allowing continuing operational service usage of the engine. The YJ101 engine modules are shown in Figures 8 and 9.

5.2.2 Engine Development. The acceptance and demonstration criteria requirement defined in the YJ101 engine model specification was the MIL-E-5007C turbojet endurance cycle. This 60-hour endurance test proved to be an adequate assessment of engine part life capabilities during the YF-17 flight test program where a 50 hour partial disassembly inspection interval was successfully used.

With the engine model specification as a base, engine and component test programs were conducted, emphasizing those areas of higher risk. Above these needs, additional endurance testing was accomplished within cost/timing restrictions to assure adequate engine/parts life and durability.

The General Electric Company's previous experience in aircraft engines enabled development of computer programs to aid in assessing the adequacy of a proposed engine test program. Inputs affecting the analysis enabled a probability of success to be established, as a function of:

- o Calendar time period of test plan.
- o Number of engines and builds.
- o Test hours.
- o Engine complexity factor.
- o Fit-it time interval.

The YJ101 test programs are detailed in the reference report.

All phases of engine and component testing are continually evaluated. Assembly and disassembly phases are monitored with procedure and design modifications made to improve maintainability. The engine modular concept is evaluated many times during quick, partial engine disassemblies and cell disassembly work. Engine test data is assessed for the impact on engine conditions at altitude and flight operating conditions. The YJ101 development program included an altitude test engine which enabled a more direct assessment of the engine's operating capability at flight conditions.

5.2.2. - Continued

Typical parts life-durability evaluations and assessments conducted during the engine test program follow:

- o Structural components strain gage evaluation.
- o Bearing thrust measurements.
- o Lube system SOAP.
- o 60-hour gear system load stand test.

Throughout the engine development program, problems were tracked to assure adequacy of investigation - in most cases, this resulted in parts redesign and retest evaluation.

As the engine development program approaches the official engine qualification stage, a thorough review of the engine life-maintainability capability is required. Each deficiency remaining must be assessed for its corrective action effectiveness or its impact on assuring adequate life with the defined maintenance plan.

Periodic assessments were performed on the YJ101 engine program to give assurance of satisfactory engine operational capability through to the 50-hour inspection point. Engine test comparisons were made to the latest engine mission requirements. Engine 101 exceeded in all cases the expected totals of a field engine with 50 hours of service. Altitude engine 005 also showed higher total operation time than the typical field engine.

5.2.3 Engine Maintenance Plan. A USAF inspection team conducting the post PPFRT engine layout review participated in the definition of the YJ101 Maintenance Plan. The Plan included pre-and post-flight inspections, organizational level inspections timed to coincide with aircraft inspections, hot section borescope inspections between major engine inspections, a more extensive "intermediate level" engine inspection at 50 hours, and a full teardown at 100 hours. A follow-on layout review of the first 100 hour flight engine resulted in agreement to extend the engine teardown inspection phase to 150 hours.

5.2.4 Flight Life-Maintainability. Close contractor coverage and support as provided in the prototype flight test program resulted in comparisons with the maintenance plan and in rapid response to correct problems. Several flight-related problems were encountered which could not have been foreseen during factory testing occurred and were resolved. The adequacy of the initial maintenance plan and the rapid response to new problems resulted in a flight program where there were no unscheduled engine removals and only one unscheduled engine shutdown.

5.2.5 Engine Life Predictions Analysis. This prototype program provided an opportunity to provide a methodology for creating continuing life definition testing support for such systems and to lay the ground work for developing test and analytical techniques which can correlate factory testing and service use to create an engineering program to establish improved engine design and maintenance capability. A flight test program such as flown on the YF-17 creates a model for this approach. The reference report provides the methodology and examples of the data used in this approach. A test cycle was constructed and an engine run for a limited number of hours to this cycle based on the flight test mission.

5.3 Conclusions.

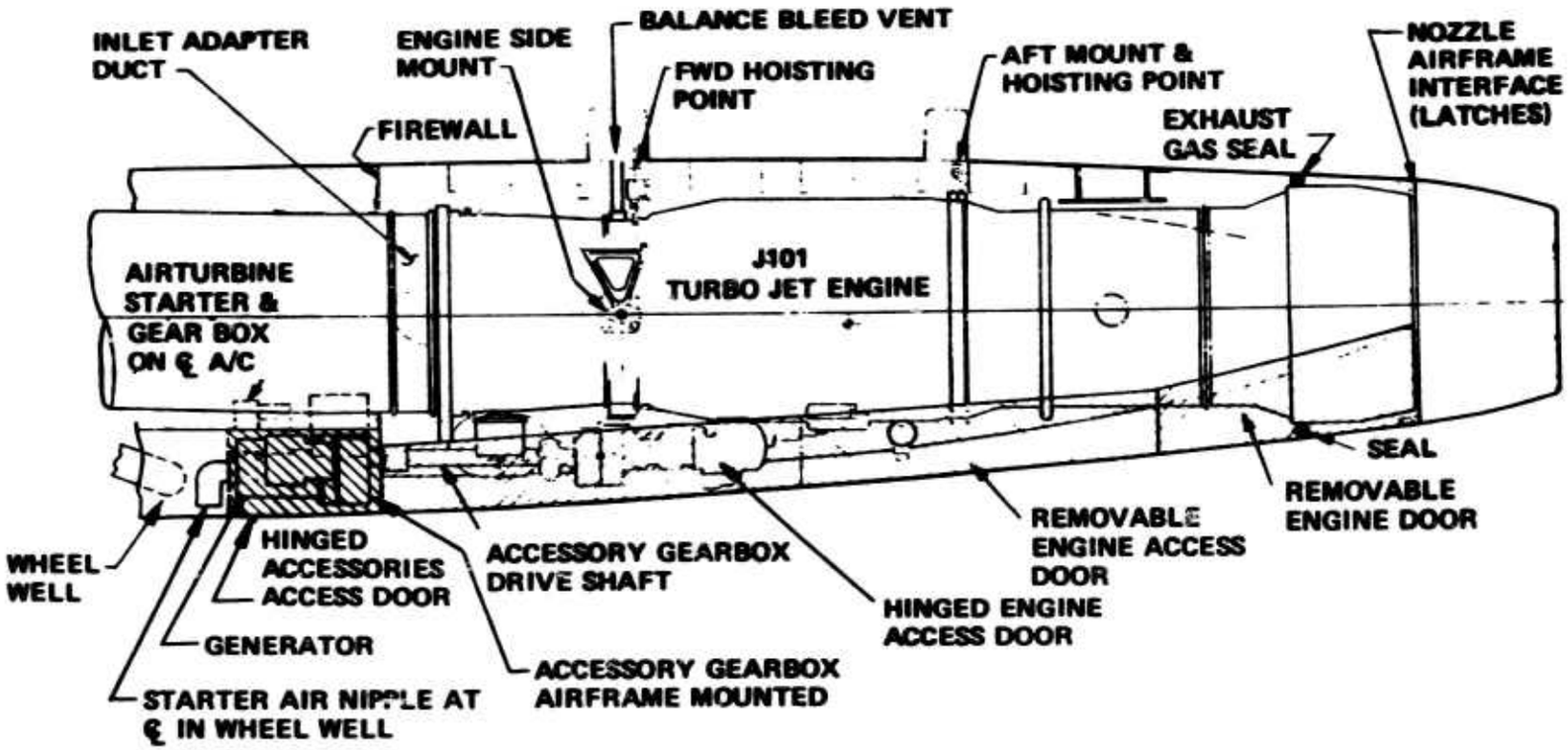
- The prototype YJ101 PPFRT engine demonstrated an excellent life-maintainability capability for the prototype YF-17 aircraft flight test program. Factory testing provided an excellent correlation base for flight engines/parts life capability.

- The USAF prototype program concept enabled effective development and utilization of the YJ101 engine capability. Rapid, successful introduction of required design modifications enabled the engine to meet requirements of the prototype flight test program.

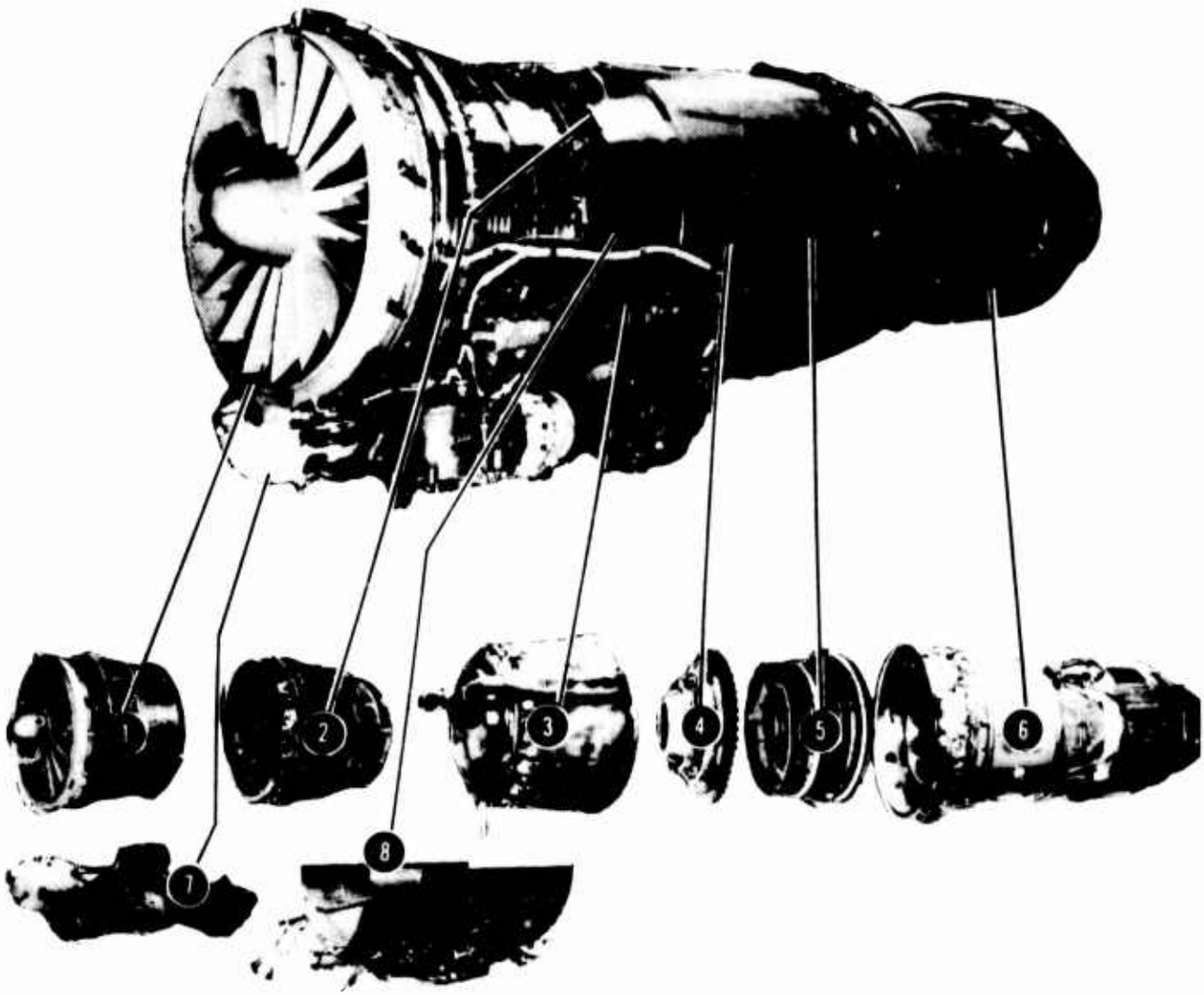
- Engine/parts life prediction analysis approaches defined enable assessments to be made on the impact of the various aircraft missions. The defined YJ101 simulated mission cycles provided an excellent duplication of field engine operational parts life/durability evaluation.

- The prototype YF-17 aircraft average engine mission was more severe than the design requirements mission.

- The MIL-C-5007C 60-hour engine endurance test cycle results in a severity on turbine parts two to three times greater than YJ101 flight experience. This endurance test, however, does not provide representative conditions cycling operation as encountered during the YF-17 aircraft flight test program.



ENGINE INSTALLATION ARRANGEMENT
Figure 8



1	LOW PRESSURE COMPRESSOR MODULE	Front frame, stator assembly, rotor assembly, variable geometry actuation system
2	HIGH PRESSURE COMPRESSOR MODULE	Midframe, number 2 bearing housing, high pressure compressor rotor, high pressure compressor stator
3	COMBUSTOR MODULE	Combustor casing, combustor liner, high pressure turbine nozzle assembly
4	HIGH PRESSURE TURBINE MODULE	High pressure turbine rotor
5	LOW PRESSURE TURBINE MODULE	Low pressure turbine casing, low pressure nozzle and support, exhaust frame, mount ring, low pressure turbine rotor
6	AFTERBURNER MODULE	Variable exhaust nozzle assembly, A/B assembly, hydraulic variable exhaust nozzle actuators
7	ACCESSORY GEARBOX AND ACCESSORY MODULE	Accessory gearbox, controls and accessories
8	LOWER DUCT	Lower Duct/Plumbing

YJ101 ENGINE MODULES
Figure 9

COMPONENT	TEST	RESULTS
1. VARIABLE EXHAUST NOZZLE SECONDARY NOZZLE SYSTEM	o STATIC LOAD TEST	o STRESS/DEFLECTION MEASUREMENT CONFIRMED DESIGN ANALYSIS
2. MID FRAME MOUNTS	o ENGINE STRESS MEASUREMENT o STATIC LOAD TEST	o ENGINE STRESS MEASUREMENT CONFIRMED DESIGN ANALYSIS o RAN TO OVER 2X MAXIMUM DESIGN WITH NO SIGNIFICANT DISTRESS
3. COMBUSTOR CASING	o PRESSURE TEST TO 500 PSI ΔP ($\sim$15% HIGHER THAN MAXIMUM ENGINE ΔP - CORRECTED FOR TEMPERATURE EFFECTS)	o STRESS MEASUREMENT CONFIRMED DESIGN ANALYSIS
4. TURBINE FRAME AND MOUNT RING	o STATIC LOAD TEST	o STRESS MEASUREMENT CONFIRMED DESIGN ANALYSIS

YJ101 ENGINE STRUCTURES
COMPONENT TEST EVALUATIONS

Figure 10

6.0 YJ101/YF-17 PERFORMANCE MATCHING

6.1 Reference. TM75AEG1180: YJ101 Engine/YF-17 Aircraft Performance Matching.

6.2 Summary. Documentation of the methods and key program factors related to the YJ101 engine performance which led to a successful engine-aircraft flight test program provided information useful to other current and future propulsion development programs. This work addresses to the engine performance approaches and development and its matching to the aircraft system needs.

It is significant to note that this flight test program was undertaken without the benefit of any previous flight "test bed" engine operation. An engine design was conceived, developed with only 1278 test hours and flown successfully for the first time in the first prototype aircraft. A great degree of the accomplishment must go to the excellent performance of the engine design; however, of equal importance was the makeup of the component and engine test program content. The continual monitoring, appraisal of the engine capability status and risk assessment as to the planned program and its timing for the engine evaluation, especially the altitude demonstration test, were also significant in assuring the accomplishment of initiating successful aircraft flight testing.

6.2.1 Engine-Aircraft Design Performance Matching. The studies that GE and Northrop began in 1968 for a modern lightweight fighter resulted in defining engine requirements that optimized performance in a primary battle area (Figure 11), cruise performance at Mach 0.8 to 0.9 at higher altitudes and transient operational capability at high altitudes and very low Mach No.'s. Considerations of cruise vs. combat SFC's and the requirements to maintain augmentor operation at low compressor inlet pressure levels eventually led to a selection of a bypass engine cycle with a bypass ratio of 0.2. Another advantage of the low bypass turbojet cycle for this application was discovered to be the favorable Intermediate to Maximum thrust ratio. Takeoffs and many of the required combat maneuvers can be made at intermediate power or low augmentation levels with attendant fuel savings.

6.2.2 Development Program Performance. Limited performance improvement was conducted during the development test program; effort was concentrated on assuring the mechanical and operational capability of the engine. However, review of the needed contribution of each of the components to the ultimate success of the program and an assessment of risk factors dictated that the full scale engine testing be preceded and augmented by component development testing on the low pressure compressor, core (high pressure compressor plus HP turbine), combustor and augmentor.

6.2.2 - Continued

With performance objectives established, component and engine designs were defined and then evaluated in component and engine test programs. Results of these tests were measured against objectives and impact on the prototype. These results and comparisons are shown graphically in the referenced report.

A YJ101 engine was tested in the AEDC USAF facility during the latter part of 1973 primarily to evaluate operational capability within the YF-17 aircraft flight envelope. Steady state starting and transient performance data, acceleration rates and augmentor transients were obtained. Engine tolerance to inlet distortion was evaluated with the use of five distortion patterns. One of these patterns was obtained from the 0.2 scale YF-17 aircraft inlet tests at AEDC. All steady state and margin testing was successful showing an engine margin capability above the model specification requirement. During the course of this testing, six stalls were intentionally induced by fuel pulsing. All stalls were recoverable and no main burner flameouts occurred.

Steady state performance data was taken at points of significant interest to the YF-17 program and around the corners of the engine flight envelope and compared to specification performance. Intermediate thrust and SFC were very close to requirements while max power SFC was poorer indicating poor augmentor efficiency. Max power at altitude was also close to requirements and SFC power. Jet nozzle leakage at low pressure levels was discovered to be excessive resulting in high altitude cruise SFC. Transient operation was checked from Mp 0.5/50K to Mp 1.2/30K. While the high altitude subsonic acceleration rates were slightly lower than predicted, all transients were smooth and regular. Augmentor transients were successfully confirmed; light-off pressure pulses were small. Figure 12 illustrates the AEDC test experience.

During the AEDC testing, max power engine control schedules were evaluated and a successful flight engine acceleration schedule defined.

6.2.3 Engine In-Flight Performance. Agreement with Northrop on the methods of calculating in-flight thrust and inlet airflow was obtained in time to permit obtaining data during the AEDC test to confirm these methods and develop a correlation curve. There was basic agreement that gross thrust would be calculated from a pressure-jet nozzle area relationship and inlet airflow would be calculated from a measured rotor speed, T2, IGV position and a compressor map. Ram drag would then be calculated from Northrop measured aircraft velocity, inlet recovery and T2. AEDC testing produced data to satsify both the gross thrust-pressure-area relationship and the airflow-speed relationship and a correlation curve was developed.

6.2.3 - Continued

About 20 flights were made during the flight test program to establish drag, range and Ps. The results were inconsistent. Additional flights incorporating a number of changes in instrumentation, engine schedules and augmentor hardware were made and rational and repeatable results obtained. This data is shown and discussed in detail in the referenced report.

6.2.4 Inlet Compatibility. Building on the experience base accumulated from extensive testing done in development of the F101 engine, a stability stacking procedure was developed which itemizes all the significant effects influencing both low pressure and high pressure compressor surge margins. The basis for quantifying the elements of these stability stacks was:

Item	Basis for Estimate
o Inlet Distortion	Component Data Engine Data
o Throttle Transients	Dynamic Simulation Engine Data
o Quality & Deterioration	Best Engineering Judgement Plus Design Tol. & Bench Tests
	△ Surge Line Quality 2.5%
	△ Surge Line Deterioration 1.0%
	△ O/P Line Control Tol. 1.5%

Fifteen flight conditions were selected as being important points at which to check compatibility. At five of these conditions or stability tracking points, unrestricted throttle movements were expected. At the other eleven points, corresponding to more extreme combinations of angle of attack and side slip, it was anticipated that throttle movements will not be required

The major component and engine compatibility tests carried out in this program are shown in Figure 13 along with some key program milestones.

The excellent compatibility capability demonstrated by the J101 can be traced to two key engine design features --

- o Exceptionally good attentuation of inlet distortion by the low pressure compressor.
- o Soft afterburner light characteristics.

6.2.4 - Continued

The AEDC altitude/distortion test program demonstrated capability well beyond earlier estimates. Highlights of this test program include:

- o Demonstrated stall free operation in the upper left hand corner of the flight envelope at inlet distortion levels some 18% greater than expected.

- o Margin demonstrations carried out on both the low pressure and high pressure compressors showed that ample surplus surge margin is available to accommodate such stability stack items as engine to engine and controls variation and deterioration.

- o Intentional stall experience demonstrated:

  - Recoverable stall characteristics.

  - Estimated stability assessments and stacking procedures are conservative.

6.2.5 Exhaust System Compatibility. Since conception, the J101 nozzle/boattail was specifically designed for the YF-17 aircraft. Consequently, it has been possible to incorporate YF-17 aircraft/mission considerations into the design to achieve a low weight, low drag YF-17 nozzle/afterbody system over the flight envelope. The design features which were made possible by this approach and which were incorporated into the YF-17 prototype design are:

- o Nozzle external boattail attached and blended to the aircraft thus assuring a smooth, continuous afterbody/boattail contour over the flight envelope with weight and drag advantages.

- o Nozzle internal area ratio schedule optimized to the YF-17 mission to achieve the most favorable internal thrust/external boattail drag combination over the flight envelope.

- o External flap construction optimized for expected YF-17 loads. Thus, minimum weight.

- o Smooth afterbody/nozzle interfairing.

Integration of these design considerations into YF-17 prototype was refined and upgraded in three phases of joint GE/Northrop jet effects model testing at AEDC. The model employed in the AEDC 16T windtunnel was a wing-tip supported, 1/10 scale aircraft model with blowing exhaust nozzle. In addition to afterbody/nozzle static pressure measurements, both afterbody drag and nozzle thrust were measured on separate force balances. Figure 14 shows the model's geometric characteristics and Figure 15 shows the model installed in the windtunnel.

6.2.5 - Continued

The primary purpose of this activity was to identify and to optimize the elements of the power matching equation for thrust/drag accounting. This testing quantified the reference drag, the boattail drag and the throttle dependent drags. In addition to the broad range of installation variables, testing of an Aero Reference Afterbody was also conducted. This aero reference model duplicated the afterbody geometry tested by Northrop to determine basic aircraft drag polars, and provided a common base model to relate the jet effects test results to the aero force model. Thus, by combining the results, the total aircraft performance including exhaust nozzle/afterbody throttle dependent effects was determined over the flight envelope.

The success of this optimization program can best be illustrated by comparing the low drag model test results with measured in-flight data. The model test results yield an aft end drag which is only 9% of net thrust at the important M = .9 subsonic cruise flight condition. To put this in proper perspective, this 9% is less than 1/3 of the F-4 or published F-111 installation loss, and is approximately the same as a representative single-engine turbofan fighter.

During the extensive YF-17 prototype flight testing, aircraft aft-end/nozzle boattail pressures were measured over a broad range of flight conditions and engine operating conditions. When integrated, supersonic flight drags were slightly lower than model data while subsonically, the model and flight test drags were approximately the same. Thus, the overall success of the joint GE/Northrop program to develop a high performance integrated nozzle/aft-end has been supported by actual flight test which indicated aft-end throttle dependent drags equal to or less than model test.

6.2.6 Conclusions. The YJ101 prototype engine achieved all significant performance and all inlet compatibility objectives with the exception of specific fuel consumption. In regard to achieving needs for the prototype aircraft flight test program, all engine requirements were met and demonstrated. The components and engine test programs showed that the mix defined was right for this prototype engine program with additional afterburner performance work performed during the latter part of the program. Emphasis is placed on the timely need and benefits of the engine altitude test as conducted on this program. This test allowed proper control system schedules to be confirmed and incorporated into the flight test engines prior to this shipment to the airframer.

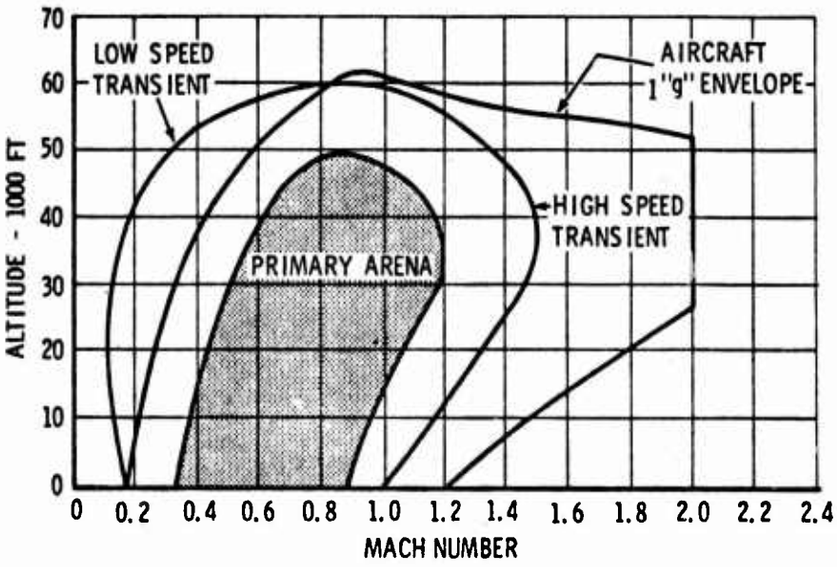
6.2.6 - Continued

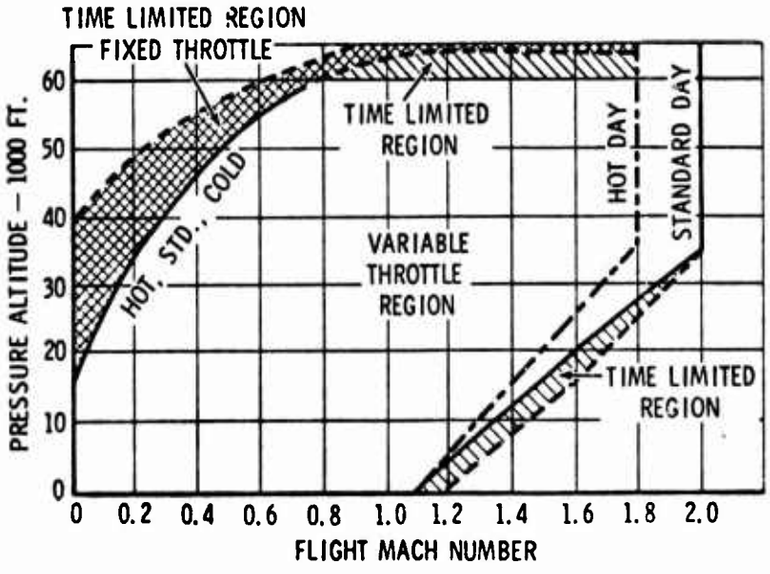
Future prototype flight test programs should address to some of the lessons learned on this program such as:

- Assure that engines are adequately instrumented for aircraft transient inflight engine performance assessments (true steady state condition data was nor normally obtained).

- Provide computer programs for engine-aircraft analysis (UFTAS requires revision to adequately handle correction from test day to standard day).

- Provide for early engine-aircraft performance testing to measure capability vs. requirements with the right on-site coverage capability.





AIRCRAFT AND ENGINE OPERATING ENVELOPES

Figure 11

AEDC TEST EXPERIENCE

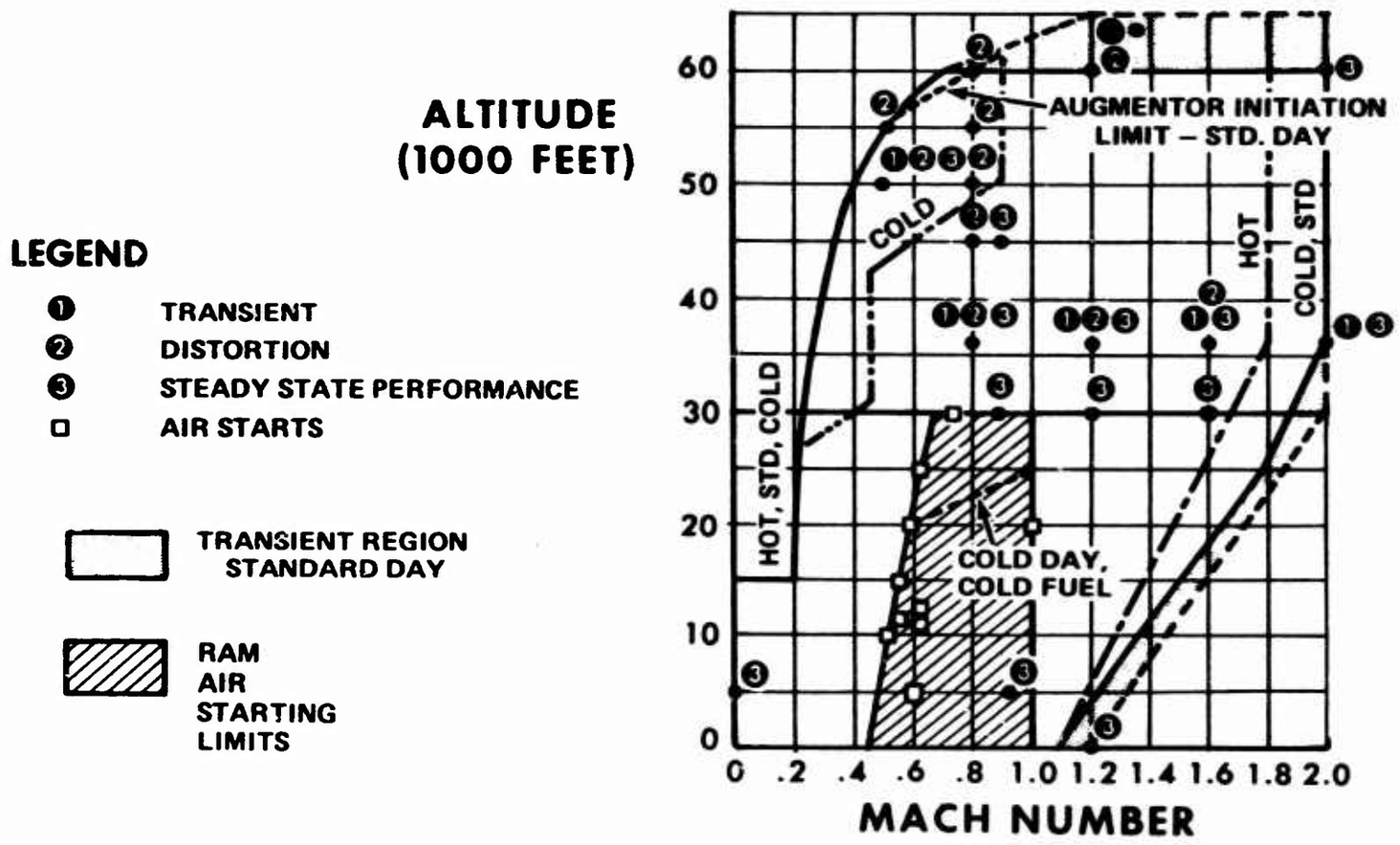
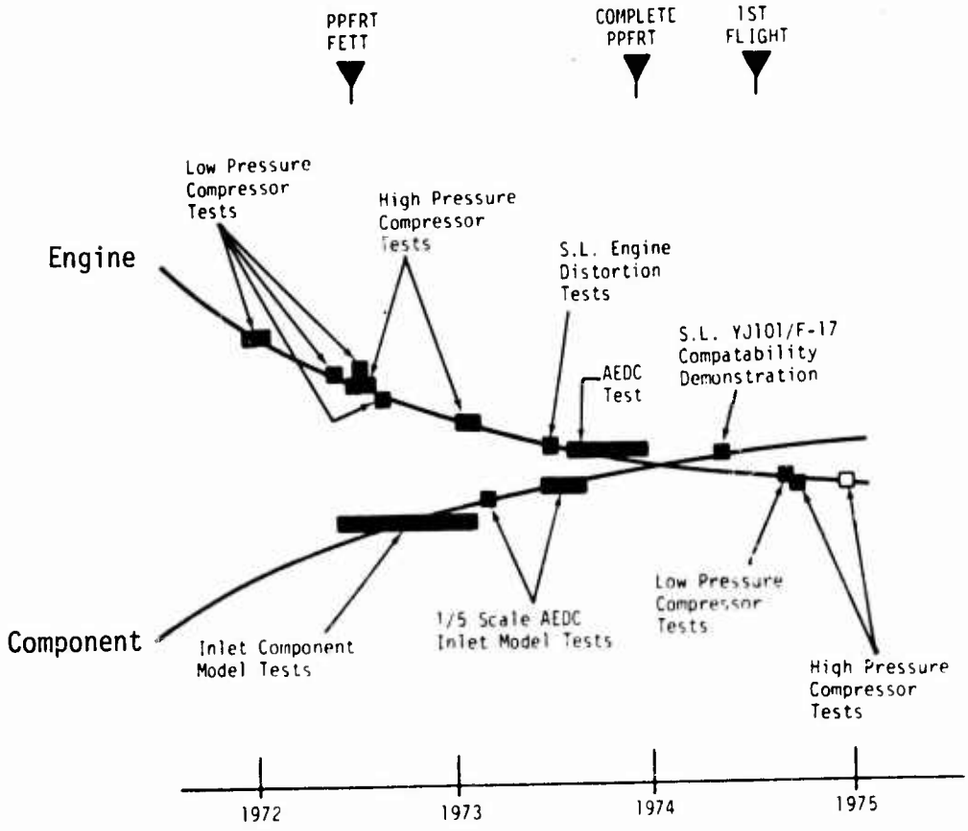
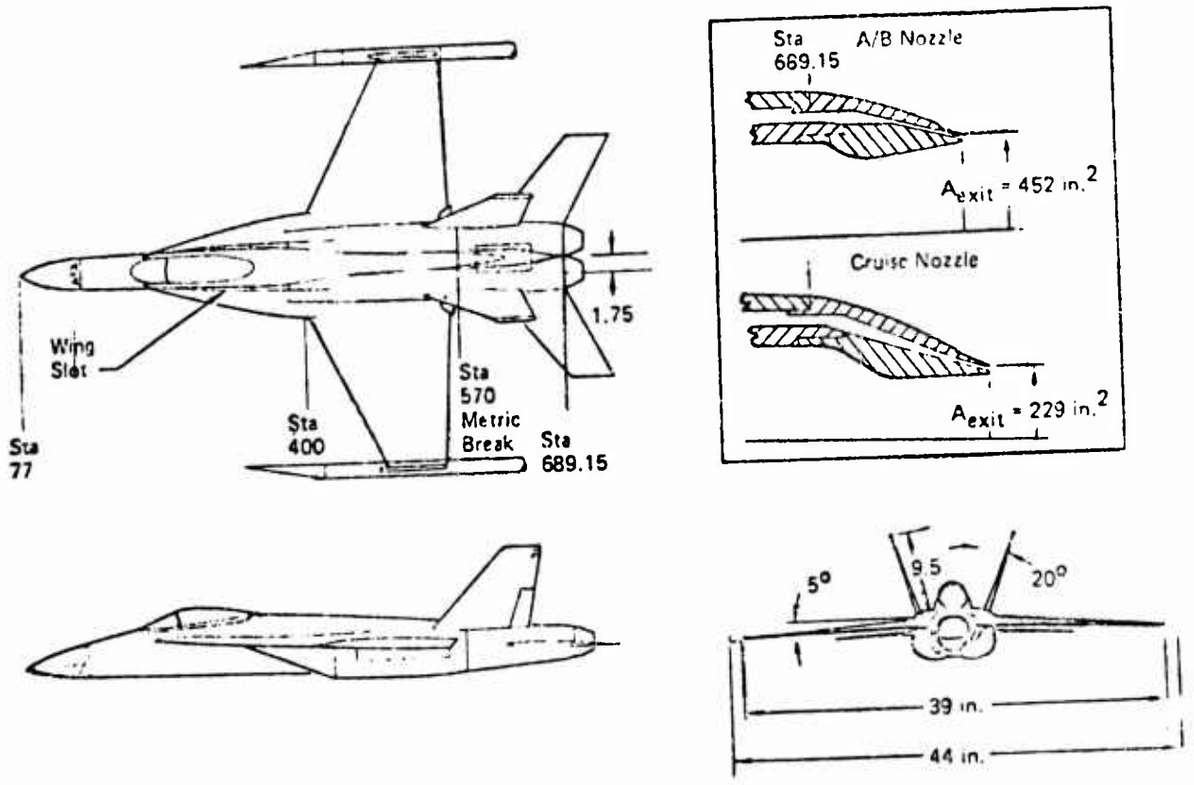


Figure 12



J101-GE-100/F-17 COMPATIBILITY "TIME TUNNEL"

Figure 13



GEOMETRIC CHARACTERISTICS OF F-17 MODEL

Figure 14



This may contain
PROPRIETARY MATTER

F-17 MODEL IN WIND TUNNEL
Figure 15

☆U.S.Government Printing Office: 1977 — 757-001/77