(14)

ASD-TR-79-5040

(2) LEVEL

(10) James L. Pettigrew
Keith Hamilton

(6) of the

PROCEEDINGS SEVENTH ANNUAL TRI-SERVICE MEETING FOR AIRCRAFT ENGINE MONITORING & DIAGNOSTICS (7th)

Held on 5-7 December 1978, and

AT ARNOLD ENGINEERING DEVELOPMENT CENTER, ARNOLD AFS, TENNESSEE.

(9) Final rept.,

(11) 19 Jul 79

AIR FORCE, ARMY, NAVY, COAST GUARD, and NASA
TECHNICAL REPORT ASD-TR-79-5040

(12) 291

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

008800

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 report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

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

James L Pettigrew

JAMES L. PETTIGREW, Lt Col, USAF
Deputy Director Engineering and Test
Deputy for Propulsion, ASD/YZE

Keith R Hamilton

KEITH R. HAMILTON
Air Force Aero Propulsion Lab, TBC

FOR THE COMMANDER

C M High

C. M. HIGH
Director Engineering and Test
Deputy for Propulsion ASD/YZE

"If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify ASD/YZE *, W-PAFB, OH 45433 to help us maintain a current mailing list".*

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

AIR FORCE/56780/19 September 1979 — 200

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ASD-TR-79-5040	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PROCEEDINGS SEVENTH ANNUAL TRI-SERVICE MEETING FOR AIRCRAFT ENGINE MONITORING AND DIAGNOSTICS		5. TYPE OF REPORT & PERIOD COVERED Final Report 5-7 Dec 1978
		6. PERFORMING ORG. REPORT NUMBER N/A
7. EDITORS Lt Col James L. Pettigrew, ASD/YZE and Mr. Keith Hamilton, AF Aero Propulsion Lab		8. CONTRACT OR GRANT NUMBER(s) N/A
9. PERFORMING ORGANIZATION NAME AND ADDRESS ORGANIZATIONS OF THE U. S. ARMY, U.S. AIR FORCE, U.S. NAVY, U. S. COAST GUARD, AND NASA		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS N/A
11. CONTROLLING OFFICE NAME AND ADDRESS Aeronautical Systems Division ASD/YZE, Wright-Patterson AFB, Ohio 45433		12. REPORT DATE 19 JUL 1979
		13. NUMBER OF PAGES 284
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

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

18. SUPPLEMENTARY NOTES

Individual presentations are cleared for public release through each presentor's organization.

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

Turbine Engine Diagnostics - Condition Monitoring - Fault Isolation - On-Condition Maintenance - Maintenance Management, Vibration, Oil Analysis - Borescopes - Performance Analysis - Maintenance Support - TEMS - ECMP - ICEMS - Maintenance Support.- Modular Maintenance - Reliability Centered Maintenance.

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

These proceedings contain an edited compilation of the presentations of government agencies at the Seventh Tri-Service Diagnostic Conference held at Arnold Engineering Development Center, Arnold Air Force Station, Tennessee 5-7 Dec 1978. The program themes were current experience service needs and technology thrusts in aircraft turbine engine monitoring and diagnostics. Working level representatives from the maintenance organization of operating and support commands gave their views on the requirements for specific diagnostic and maintenance decision information.

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

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

FOREWORD

This report is an edited compilation of the presentations unless otherwise noted, of Government agencies, given at the Seventh Tri-Service Diagnostic meeting held at Arnold Engineering Development Center, Arnold Air Force Station, Tennessee, 5-7 December 1978. Each presentation contains an overview of the results and conclusions of the aircraft turbine engine diagnostic efforts that have been accomplished and that are being performed or planned. A compilation of the after dinner panel discussions given by representatives of military logistics management organizations are also included to provide further insight into the usage needs of military services for turbine engine monitoring applications.

The editors of this report wish to acknowledge the efforts of all presenters and attendees who contributed to the success of this meeting. The highly professional type of support and accommodations provided by the USAF AEDC through the Commander, Colonel Oliver H. Tallman II, and Mr. Alan E. Bu[illegible]ll, AEDC/DOTA, as well as the valuable assistance of Mr. Tom Belrose, US Army, Aviation Readiness/Development Command, Mr. A. J. Hess, US Navy Air Systems Command, and all other agency coordinators is deeply appreciated.

TABLE OF CONTENTS

SECTION 5 - TECHNOLOGY THRUSTS

SECTION 6 - MISCELLANEOUS

NOTE: A highlight summary and editorial notation on each presentation is provided. Our thanks to Mr. Douglas Barnes ASD/ENFPJ for the use of his trip report and his assistance in developing these short write-ups.

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AERONAUTICAL SYSTEMS DIVISION (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

8 SEP 1978

REPLY TO
ATTN OF: YZE

SUBJECT: Seventh Annual Tri-Service Meeting on Aircraft Engine Monitoring/Diagnostics

TO: Tri-Service Coordinators

1. A meeting was recently held with the host organization and Air Force Coordinators for details of the Seventh Meeting, which is being planned with inclusive dates of 5 through 7 December at Arnold Air Force Station, Tennessee.

2. The proposed themes and guidelines for the meeting are:

a. Program Themes:

(1) Current Experience. (Where we are today.) Emphasis on summary of technical aspects, trade studies, and life cycle costs (lessons learned), de-emphasis of schedules, costs, and lengthy details.

(2) Service Needs. (What we need to work on.) Emphasis on who needs what information and facilities for aircraft engine operation, maintenance scheduling and support.

(3) Technology Thrusts. (How we plan to satisfy the needs.) Emphasis on on-going/planned developments.

Each Service is requested to participate in each theme element rather than be allotted a day per Service as in past meetings.

b. A guided tour of the unique altitude test facilities and Arnold Engineering Development Center (AEDC) involvement in engine condition monitoring and diagnostics is being planned.

c. Arnold Air Force Station personnel are planning a dinner on the evening of the 6th December 1978, at which working level representatives of Air Force Operating Commands will be invited to talk about specific diagnostic and maintenance decision informational needs and be available as a panel to discuss these needs with all participants. It is anticipated that these talks and discussions can be recorded for inclusion in the published minutes of the meeting.

d. It is proposed that the Air Force Coordinators will compile the information exchanges and publish these as the proceedings of this meeting. As such this document can not only be a very valuable reference for usage by working level scientists and engineers, but can also provide pertinent information to each of the Service's upper levels of command and management normally required by separate and time consuming reports and reviews. In order to publish this kind of a document each presenter should provide the following at the meeting:

(1) A typed single spaced expanded abstract not longer than 10 pages inclusive of only the key viewgraphs representing the key points of his presentation. The abstract may be somewhat informal in nature, but should not contain classified, sensitive, or official information.

(2) No information that is held proprietary by an industrial organization should be included.

(3) Appropriate clearances for publication and unlimited distribution should be obtained by each presenter through his organization of assignment so the material can be compiled into a report for unlimited distribution.

(4) The inputs of each of the military service presentations should be compiled by each Coordinator with recommendations as to the appropriate section of Paragraph 2A and forwarded to Mr. K. R. Hamilton, AFAPL/TBC, Wright-Patterson AFB, Ohio 45433 not later than the 18th of October 1978.

3. So that billeting reservations can be planned, it is requested that each Service Coordinator provide an estimate of the number of attendees, and the names with official mailing addresses of those who will be either attending or who should be invited, if they are not shown on the previous attendance list.

4. Your added comments, recommendations, or suggestions to make this meeting a success are earnestly solicited. Please contact either myself at Hqs ASD/YZE, Autovon 785-2900 or K. R. Hamilton at AFAPL/TBC, Autovon 785-4061.

James L. Pettigrew

JAMES L. PETTIGREW, Lt Colonel, USAF
Deputy Director of Engrg & Test
Deputy for Propulsion
AF Tri- Service Coordinator

Cy to: AEDC/DOTA

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS ARNOLD ENGINEERING DEVELOPMENT CENTER (AFSC)
ARNOLD AIR FORCE STATION, TENNESSEE 37389

REPLY TO
ATTN OF: CC

13 NOV 1978

SUBJECT: Seventh Annual Tri-Service Meeting on Aircraft Engine Monitoring and Diagnostics

TO: SEE DISTRIBUTION

1. The Annual Tri-Service Meeting on Aircraft Engine Monitoring and Diagnostics, held each fall, serves as an important forum for cross-fertilization of interservice efforts, for exposing propulsion engineering and maintenance-oriented people to operation and support problem areas and service needs, and for focusing on the management requirements for increasingly complex propulsion systems. This meeting is intended to encourage the maximum exchange of information and experience as a tool for more effective advancement of the state-of-the-art in engine condition monitoring and diagnostics and minimize duplication of efforts for economy of resource dollar outlays.

2. You are cordially invited to attend and participate in this Seventh Tri-Service Meeting which is being hosted by the Arnold Engineering Development Center at Arnold Air Force Station on 5 through 7 December 1978 in the Main Auditorium.

3. A brief agenda is attached indicating the currently anticipated subjects to be covered in keeping with the themes of:

a. Current Experience - Where are We Today?

b. Service Needs - What Should We Work On?

c. Technology Thrusts - How We Plan to Satisfy the Needs.

4. Visual aids equipment for viewgraphs will be provided. Participants are requested to leave one reproducible copy of a typed, single-spaced synopsis of their presentations that is not longer than 10 pages inclusive of only key viewgraphs. This synopsis may be somewhat informal in nature. It should not contain classified, sensitive or official information. No information that is held proprietary by an industrial organization should be included. Appropriate clearances should be obtained by each presenter through his organization of assignment so that the material can be compiled into a report for unlimited distribution.

5. For billeting arrangements, the point of contact at Arnold AFS is Mr Al Burwell (DOTA), AUTOVON 882-1520, extension 7791. Please indicate whether you will attend the scheduled dinner at which some of the service needs and problems will be discussed by representatives of the service operating commands. The cost of the dinner will be $7.00 (including tip).

6. Thank you for your consideration and support in making the Tri-Service Meeting a successful and valuable exchange of information.

Oliver H Tallman II

OLIVER H. TALLMAN II, Colonel, USAF
Commander

3 Atch
1. Meeting Agenda
2. AEDC Directory Map
3. Area Map

PRESENTATIONS OF 7TH TRI-SERVICE DIAGNOSTIC MEETING

5-7 DECEMBER 1978

Tuesday, 5 December

0845-0900	Welcome/Opening Remarks
0900-0915	Administrative Announcements (No Paper)
0915-1000	Current Monitoring and Sensing Techniques - T, Belrose, AVRADCOM
1000-1030	Break
1030-1115	Navy ULAIDS Status - D. Watters, NATC
1115-1230	Lunch
1230-1300	NASA Engine Diagnostic Program - E. Szanca, NASA
1300-1400	Strategic Air Command ECMP -SN SGT T. Strauss, SAC
1400-1430	T38 EHMS Program Update - SMSGT K. Pobanz, TAC
1430-1500	Break
1500-1545	A-10 TEMS Evaluation - Capt J. Gissendanner, AFLC
1545-1600	Terminology for Scoring Diagnostic System Effectiveness - Capt J. Gissendanner, AFLC
1600-1630	Ground Test Facility Support to Development of TEMS - Alan Burwell, AEDC
1630-1700	B-1 CITS Flight Test Results - Lt Col J. Pettigrew
1700-1730	ADEMS II Flight Test Update - 1/Lt J. Edens, ASD

Wednesday, 6 December

0830-0900	Navy Ground Support Equipment for Engine Monitoring - H. Kohler, NAVAIR (No Paper)
0900-1015	F-18 ICEMS - A. Hess, NAVAIR (No Paper)
1015-1045	Break
1045-1215	Performance Trending - W. Pasela
1215-1315	Lunch
1315-1400	Engine Analytical Maintenance - L. Doubleday, NAVAIR
1400-1445	Navy A7E ICEMS Experience - A. Hess, NAVAIR (No Paper)
1445-1630	AEDC Facility Tour
1900-2000	Dinner Program
2000-2130	Panel Discussion of Service Needs - MAC/LGM, SAC/LGM TAC/LGM, ATC/LGM, NARF, NASC

Thursday, 7 December

0845-0930	TEMS Conceptual Engineering - W. Stevenson, AEDC - No Paper
0930-1015	Advanced Propulsion Monitoring - K. Hamilton, AFAPL.
1015-1045	Break
1045-1115	Coast Guard Status of Garrett EHMS - AD1 C. Criminale, C.G.
1115-1215	Conclusions & Recommendations (Part 1).
1215-1300	Lunch
1300-1315	Advanced Trend Analysis - C. Skira, AFAPL
1315-1345	Life Usage Tracking/Accounting - W. Troha, AFAPL
1345-1430	Conclusions & Recommendations (Part 2)

PROGRAM INTRODUCTION
LT COL JAMES L. PETTIGREW
ASD/YZE WPAFB OH 45433
AF TRI SERVICE PROGRAM COORDINATOR

Good morning and welcome to the 7th annual Tri-Service Engine Diagnostics Meeting. This tri-service meeting is chartered to provide a forum for crossfeed of technology and lessons learned in the diagnostics area. You should each have a copy of the program which has sufficient variety of topics and presentors to give a warm feeling that this meeting may meet the chartered objective.

The diagnostic problem has a wide range of approaches and an extensive list of purposes. The purposes or objectives are the design drivers which allows the choice of a simple manual diagnostic system or an automated complex on-board system capable of telling maintenance which part technical order and tool is needed to repair the fault. The manual SAC System's purpose was propulsion system reliability improvement with the objectives: (1) Failure prediction before occurrence, (2) Reduce air aborts and inflight shutdowns, and (3) Improve maintenance management by providing a basis for on-condition maintenance. These SAC objectives can be contrasted to thirty-one TAC/AFLC requirements for the F100 engine ranging from fault isolation to the line replaceable unit (LRU) to a cockpit warning of specified events. The Statement of Need (SON), in Air Force terms, is then the main driver which determines the complexity of engine monitoring or diagnostic equipment fielded with a weapon system or cancelled because of lack of funds.

Maintenance concepts also have an important bearing on the requirements of the diagnostic system. Hard time maintenance is based on monitoring the number of flying hours which represents usage. A time interval representing usage significantly less than the engine's proven capability for reliable operation for another time interval. Infant mortality forms the well-known bath tub reliability curve.

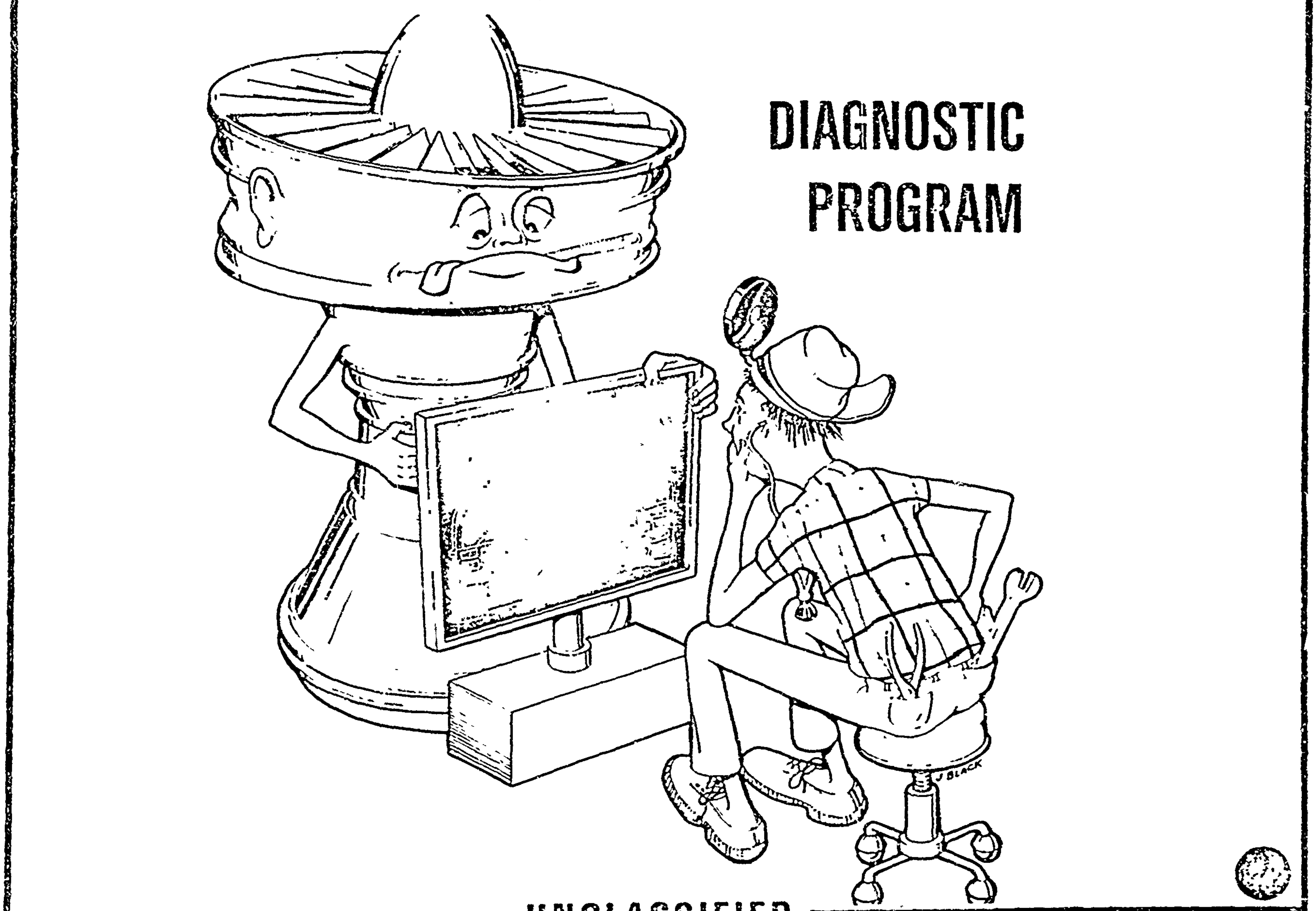
Usage is a variable depending how the aircraft is being flown. For example, at sea level point eight mach TF30 engine at military power has a compressor discharge total pressure near 500 lbs/in^2 and a total temperature of near 950^{o}F. These values compare to 145 lbs/IN^2 and 535^{o}F for the same conditions 30,000 foot altitude. The usage associated with an hour at sea level obviously is more severe than an hour at 30,000 feet. Sea level static accelerated mission testing (AMT) is equivalent to testing at point eight mach and 11,200 foot altitude. Under AMT, the test usage is equivalent to flying the engine from a high altitude air field like Denver and never going above 11,000 foot altitude. Why all the discussion on usage?

Engine usage can vary significantly for each flight hour, therefore, flight time does not necessarily indicate the engine life remaining. Other approaches such as cycles or time at temperature are being used or proposed as indicators of engine life remaining.

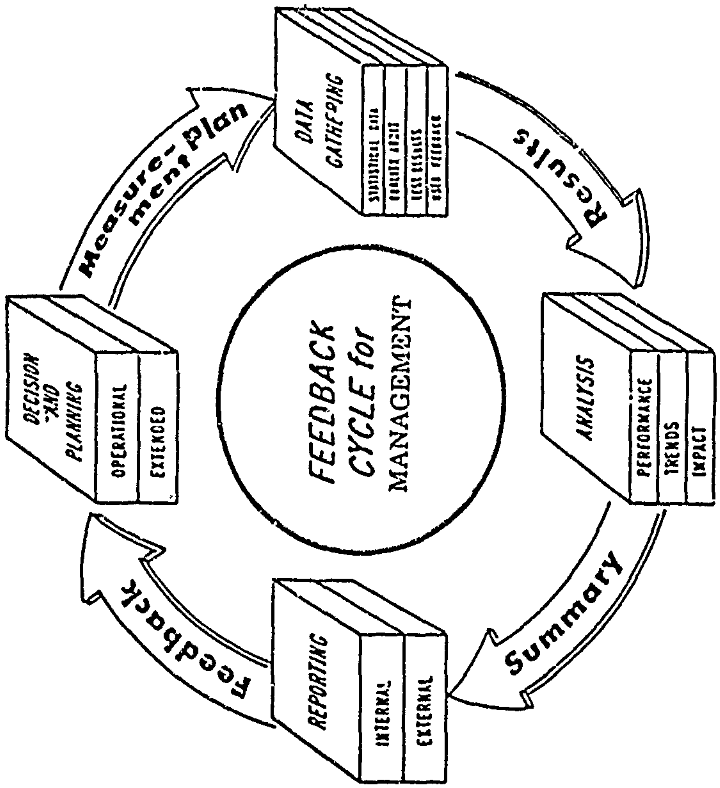
The performance trending part of engine monitoring has the capability to detect gas path deterioration. Reliable detection of deterioration before failure is the basis for on-condition maintenance. On-condition maintenance takes advantage of the variations in engine capability and engine usage. Engines which are more capable and used less severely get to fly longer before repair. Fewer repairs results in significantly lower overall maintenance cost. The motivations for diagnostics systems are obviously broad going from flight safety through more reliable engines, all the way to lower cost operation from better maintenance management. One of my major concerns is why are we so slow in getting engine diagnostic capabilities into the operational environment and reaping their benefits.

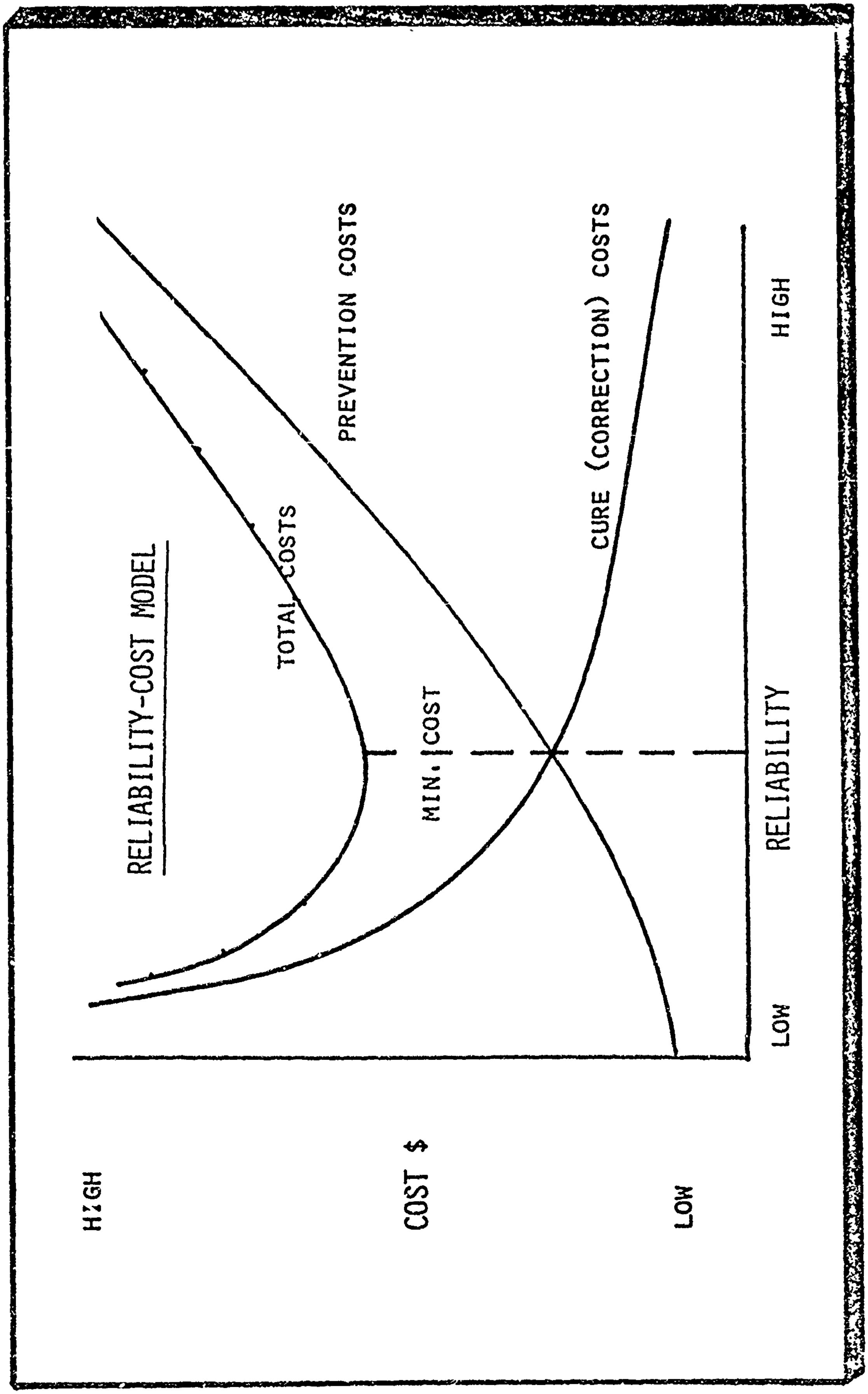
Again, I want to echo Col Tallman's words welcoming you to this meeting. Ray Wulf of General Electric, Evendale, said "He who learns something after he knows it all,, is wisest of all." It is my hope that our program will provide you some additional diagnostic information. We will begin the program with Mr. Tom Belrose telling us what the Army is currently doing in propulsion monitoring and sensing techniques.

UNCLASSIFIED

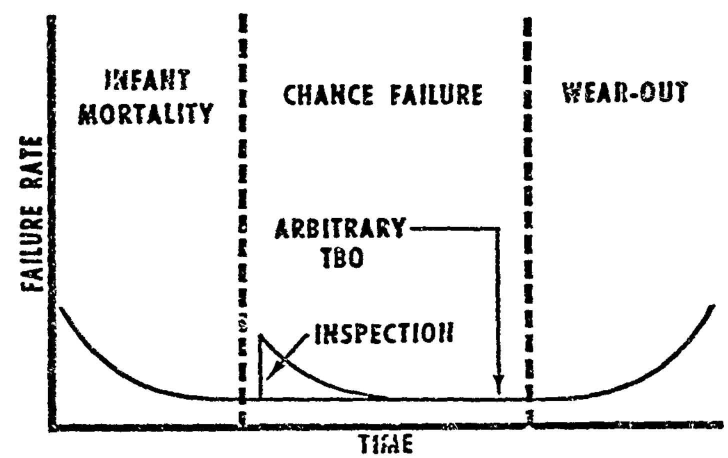


UNCLASSIFIED


FEEDBACK CYCLE for MANAGEMENT
DATA GATHERING
Results
ANALYSIS
PERFORMANCE
TRENDS
IMPACT
Summary
REPORTING
INTERNAL
EXTERNAL
Feedback
DECISION AND PLANNING
OPERATIONAL
EXTENDED
Measure-ment Plan

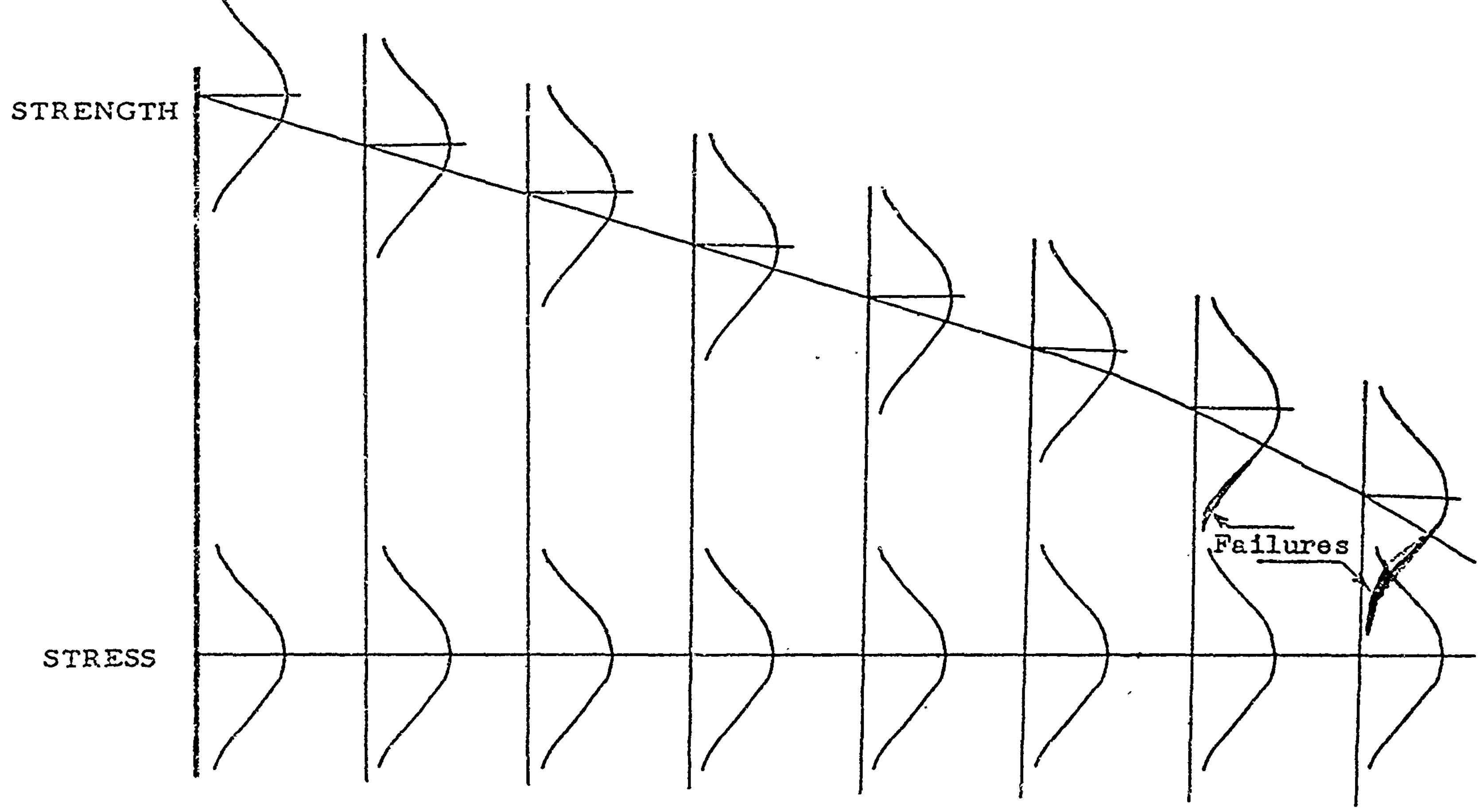

RELIABILITY-COST MODEL
HIGH
COST $
LOW
TOTAL COSTS
PREVENTION COSTS
CURE (CORRECTION) COSTS
MIN. COST
LOW
RELIABILITY
HIGH

HARD TIMES MAINTENANCE



INSPECTION AND OVERHAUL INTERVAL SELECTED TO ASSURE REPLACEMENT BEFORE FAILURE.

Stress-Strength Relationship Vs. Time



DRENICK'S THEOREM

Drenick's Theorem states that whatever the form of the failure rate during the early part of the life of a complex repairable system, the failure rate will tend towards a constant rate as the cumulative time of operation of the system becomes sufficiently large.

COMPLEX ASSY WITH ANY FORM OF HAZARD FUNCTION

MULTIPLE REPAIRS

CONSTANT PROBABILITY OF FAILURE WITH AGE

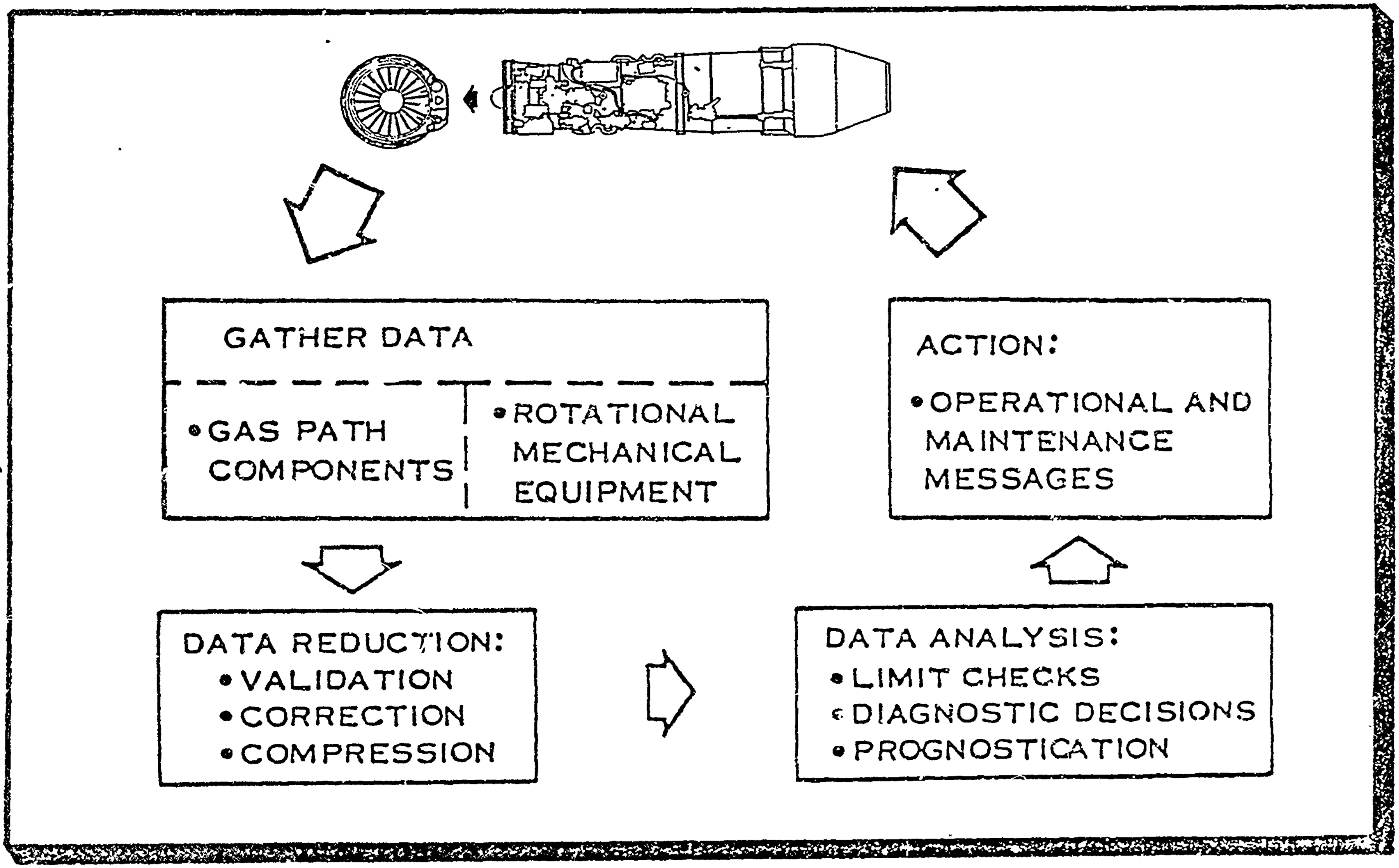
The underlying idea behind Drenick's theorem is that the failed parts will be replaced and eventually a complex assembly will not have a single age but a random mix of ages and, therefore, a constant (random) failure rate.

R. F. Drenick, "The Failure Law of Complex Equipment", Journal, Society for Industrial and Applied Mathematics, Vol. 8, No. 4, pp. 680-690.

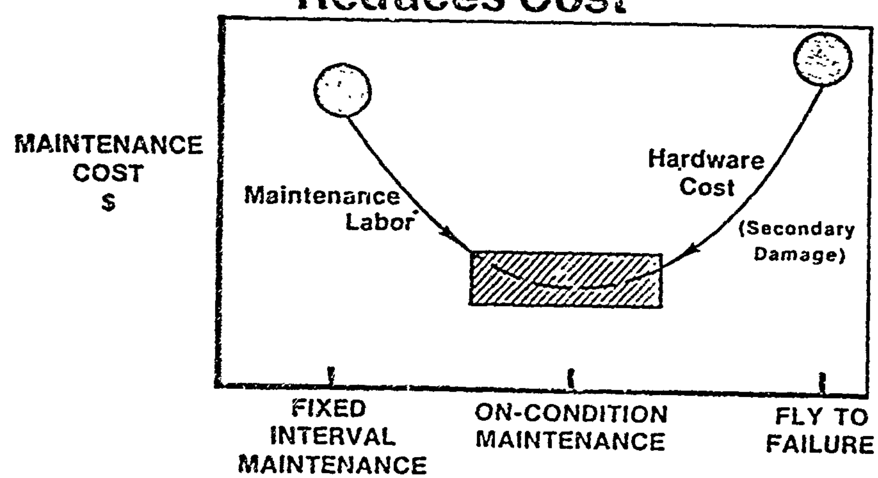
ENGINE CONDITION INDICATORS

- INSERVICE RELIABILITY EXPERIENCE
- FLIGHT CREW WRITE-UPS
- OIL CONSUMPTION - USAGE PER FLIGHT HOUR
- SPECTROMETRIC OIL ANALYSIS PROGRAM (SOAP)
- GROUND ENGINE PERFORMANCE CHECKS (TRIMS)
- VISUAL PERIODIC INSPECTIONS (BPO, NDI, BORESCOPE, TEARDOWN).
- PERFORMANCE TRENDING - INFLIGHT INSTRUMENT READINGS. (SUPPLEMENTAL TOOL - REPLACES NONE OF THE ABOVE).

ENGINE CONDITION MONITORING



On-Condition Maintenance Reduces Cost



EFFECTIVE USE OF MANAGEMENT INFORMATION

DEFINE INFORMATION SYSTEM (REPRESENTATIVE, USEFUL, ACCURATE).

ESTABLISH A REFERENCE CONDITION (PLAN/GOAL/OBJECTIVE).

OBSERVE (CAPTURE INFORMATION RELATED TO ACTUAL CONDITION)

CORRECT (NORMALIZE INFORMATION TO COMMON BASE).

COMPARE (NORMALIZED INFORMATION COMPARED TO REFERENCE PRODUCES A QUANTIFIED DEVIATION/ERROR).

CONTROL (TAKE ACTION TO ELIMINATE DEVIATIONS).

FEEDBACK (REPEAT PROCESS, USE A FREQUENT SAMPLE INTERVAL, ESTABLISH REALTIME TRENDS - SEE RESULTS OF CONTROL).

ENGINE MONITORING DATA REQUIREMENTS FOR THE MAINTENANCE ENVIRONMENT

PARAMETER	USAGE	TRACKING	TRENDING
Mach No.	+		+
Altitude	+		+
OAT	+		+
EGT (TIT,FTIT)	+	+	+
PLA	+	+	+
N(HR) (N_2)	+	+	+
N(LR)(N_1)		+	+
Fuel Flow			+
EPR or P_{T7}			/
Interstage Compressor Pressure			/
Interstage Compressor Temperature			/
Vibration			+
Oil Consumption			+

Legend: "+" signifies need to monitor this parameter; "/" signifies this parameter can be of definite benefit in trending engine performance.

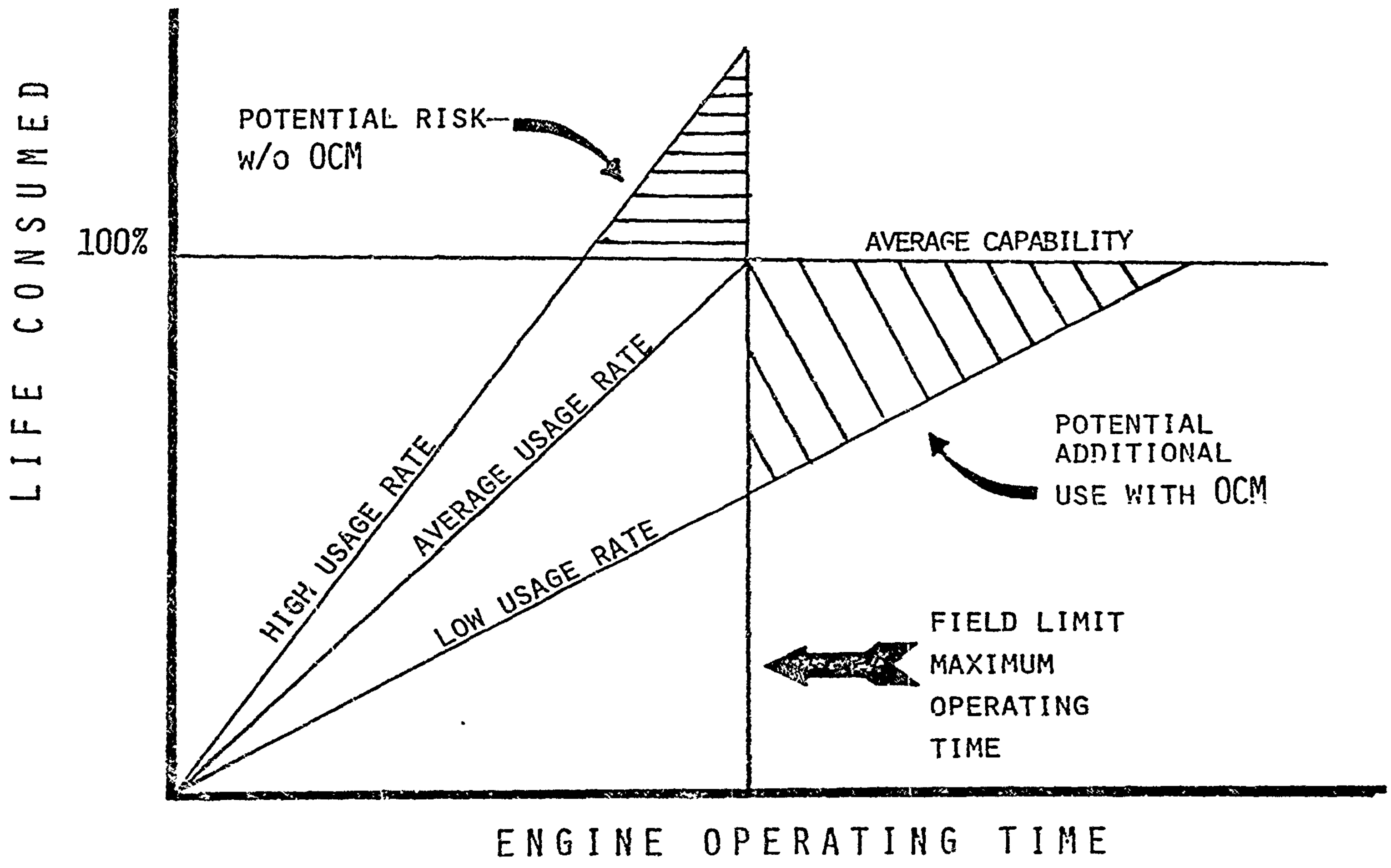
Definitions:

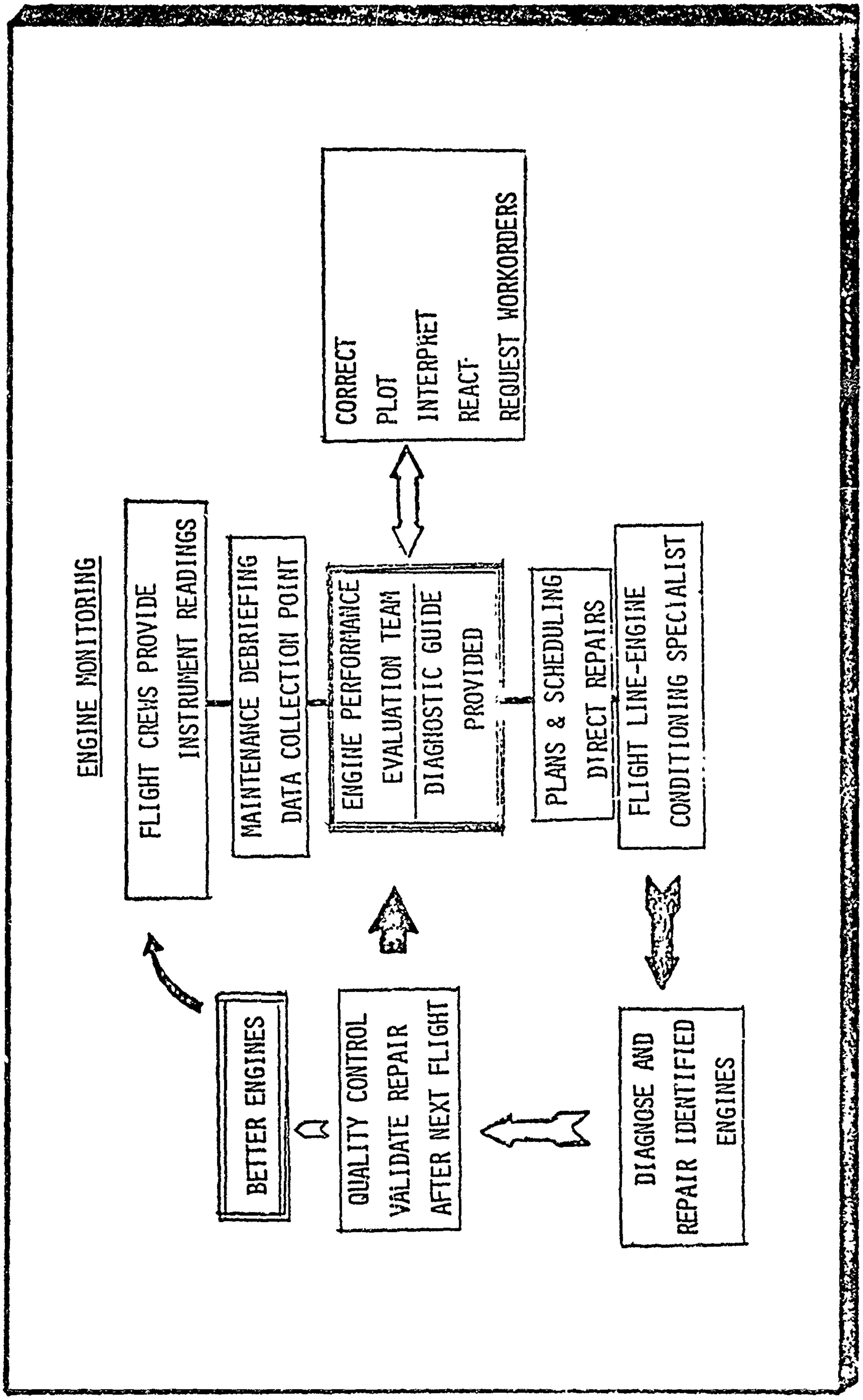
Usage: Data obtained from selected aircraft early in the program. Used to determine engine component and/or part lives. Enables establishing accelerated mission test (AMT) program.

Tracking: Data obtained at specific operating conditions on all engines installed. Used to determine when cycle or time limits have been reached on life - limited engine components and/or parts. Aids in forecasting engine logistics support requirements.

Trending: Data obtained on all installed engines by manual or electronic recording system. Used to enable conditional (on condition) maintenance concept to function.

ON - CONDITION MAINTENANCE (OCM) REDUCES RISK . . SAVES $ $




ENGINE MONITORING
FLIGHT CREWS PROVIDE INSTRUMENT READINGS
MAINTENANCE DEBRIEFING DATA COLLECTION POINT
ENGINE PERFORMANCE EVALUATION TEAM
DIAGNOSTIC GUIDE PROVIDED
CORRECT
PLOT
INTERPRET
REACT-
REQUEST WORKORDERS
PLANS & SCHEDULING DIRECT REPAIRS
FLIGHT LINE-ENGINE CONDITIONING SPECIALIST
DIAGNOSE AND REPAIR IDENTIFIED ENGINES
QUALITY CONTROL VALIDATE REPAIR AFTER NEXT FLIGHT
BETTER ENGINES

"He who learns something
after he knows it all
is wisest of all"

CURRENT MONITORING AND SENSING TECHNIQUES

BY

T. BELROSE

US Army Aviation Readiness and Dev Cmd
St Louis Mo

AV 698-6486

HIGHLIGHTS

Application of vibration, shock and chip detectors to helicopter engines and gearboxes was discussed. Vibration pattern recognition has high development costs; is difficult to implement; and involves complex hardware. Vibration demodulation technique is effective and inexpensive but with a loss of data at the mechanical interface. Dynamic balance of components influences the monitoring approach. Shock pulses and high frequency resonances above preset levels initiate a fault indicator. The incipient failure detector utilizes a spectrum analyzer and display

The T700 engine has an events history recorder and uses the SPADE (Small Portable Analyzer Diagnostic Equipment) on the flight line to detect degraded bearings, worn gears, non-alignment and unbalance. The SPADE is based on the Intel 8080 IC and uses (on the UHI) ten clamp on accelerometers. The accelerometers are not holding up probably from the wear and tear of the constant installs and removals.

A chip detector development at Fort Rucker uses a controlled spark debris burner. The T700 engine has 3 micron filters leaving no debris in the oil for SOAP analysis. Borescope inspections are OK but radiographic inspections are too complex and too costly. Temperature VS Torque data obtained under the HIT program is useful to detect engine problems.

PROPULSION SYSTEM DIAGNOSTICS

IN THE US ARMY

The US Army has recognized for sometime the need for improved condition monitoring and diagnostic equipment for helicopter propulsion systems. Recent studies have confirmed that an unacceptably high false removal rate exists on many helicopter propulsion components and the "phenomonal savings" would accrue to the Army by improving diagnostic effectiveness. There have been several attempts at developing comprehensive system which were never completed. The current approach is to develop cost-effective, affordable, suitcase type ground support equipment. The purpose of this paper is to briefly review the current Army diagnostic techniques and systems, current development programs, and future plans.

The present Army engine condition monitoring system consists of the following traditional approaches:

a. Time Between Overhaul (TBO) Concept.

b. Physical Inspection of Components.

c. Manual Trending of Performance Indicators.

d. Simple Chip Detectors.

e. Spectrometric Oil Analysis Program (SOAP).

f. Judgement of experienced personnel.

As everyone knows, these systems are adequate to assure flight safety particularly when cost is not the primary consideration. Each of these approaches have deficiencies which show-up as increased maintenance cost, reduced aircraft availability or higher parts consumption.

The TBO concept, which statistically determines the removal time prior to equipment failures, is very conservative and results in the removal of components which are suitable for service if their condition could be monitored. This raises costs by removing components which could still be used. The physical inspections detect most incepient failures but consume many manhours and increase the aircraft downtime. Manual trending is the most efficient of the current techniques but is limited by the sensitivity of the monitored parameter. Unfortunately, the Army does not maintain data on the absolute effectiveness of the system and thus the payoff cannot be determined. The chip detectors have the problem of unacceptably high false alarm rate and the inherent inability to detect non-ferrous debris. For example, during a four year period the number of correct indications for various aircraft ranged from 13% to 20% of the total number of indicators. The SOAP has the problem of delays in receiving results of the test and may not be able to discriminate some normal wear modes from failure modes particularly on high time components. The final method relies on experienced personnel. Unfortunately, these people are not always available. Also there are very few absolute measurements to be made and the decisions can be somewhat subjective. These problems coupled with the advances in electronics justify the attempts at fielding more sophisticated propulsion test equipment.

The program which is nearest to completion is the Small Portable Analyzer Diagnostic Equipment (SPADE) development effort. The SPADE is an item of ground support equipment designed to semi-automatically inspect and diagnose bearing faults in selected aircraft components. It functions on the principle of detecting and measuring shock pulses generated by the release of kinetic and frictional energy within the monitored component. Briefly the theory of the Shock Pulse is that when the rolling elements in a bearing contact a surface discontinuity, repetitive impacts of short duration and very short rise time are created, hence the shock pulse. This signal then propagates through the mechanical structure. It decays as a function of the distance it travels and is further attenuated at each mechanical interface. The signal is detected with an accelerometer and with appropriate processing is correlateable to mechanical condition.

The SPADE is a derivative of the commercial SKF MEPA-10A. It functions on the shock pulse principle as does the MEPA-10A but it is implemented in a slightly different fashion. Where the MEPA-10A requires manual data collection and interpretation of data, the SPADE is automated. Specifically, the MEPA-10A requires the interpretation of a plot of the rate of the shocks vs. the amplitude of the shocks. The critical factors are the area under the resultant curve and the shape of the curve. The SPADE measures the area by driving a voltage to frequency converter with a demodulated signal and measuring the output directly with a counter. This measurement is proportional of the level of the defect and is compared to preset limits that are representative of good, marginal and discrepant conditions. The status of the monitored components is then displayed on the instrument control panel.

Contractor Demonstration Phase: This phase began with delivery of first SPADE in February of 1978 and was concluded in September 1978. During this time parts with known defects were implanted in various UH-1 gearboxes. Baseline data was also taken on the UH-1, AH-1 and OH-58. The purpose of this phase was to finalize the limits and to demonstrate that the SPADE was ready for the Government testing phase. The SPADE was operated without preprogrammed limits so that the maximum amount of information would be available for correlating the SPADE measurement with the actual part condition. Three different accelerometers were also evaluated.

The following is a summary of the implant testing results on the UH-1H drivetrain components:

Component	Correct Indication	Incorrect Indication	Instantaneous Probability of Detection (P_{4i})
Main Trans	15	3	.83
42 Gearbox	10	0	1.00
90 Gearbox	9	1	.90
Hangar Bearings	0	0	0
TOTALS	34	4	.89

NOTE: The results of the hangar bearing test will not be proven until after the bearings are analyzed.

SPADE Fault Detection Capability: The implant approach is not a perfect test technique in that certain variables which are difficult to quantify are introducted. Thus each case must be carefully evaluated to eliminate as many of these as possible. The process of implanting a discrepant component into an "alien" gearbox results in decreased levels of kinetic energy due to misindexing of the defect relative to its natural location in its "native" gearbox, removal of trapped debris generated by the defect, and various tolerance and clearance changes which are a direct result of the component disassembly.

This above data was, for the most part, accumulated from bearings with defects that were small relative to the levels of damage which would result in loss of load carrying capability for a bearing. Since SPADE readings are proportional to the level of damage within a bearing, higher readings and higher detection rates would result if larger defects were implanted or if implants when tested were allowed to progress to more significant levels of damage. Therefore, the actual accuracy of naturally occuring defects may be different and would be better determined by a different test technique.

Although these results approach the design requirements, another concept should be considered; that is the cumulative probability of detection. The detection probabilities listed are for each time that a SPADE measurement is taken on a discrepant bearing. However, since bearings do not fail instantaneously, the SPADE can be used several times (on a regularly scheduled basis) between the time an intial discrepancy appears and the time a bearing is so badly damaged that it looses its load carrying capability. This period between initial discrepancy and loss of function for a bearing is called the Failure Progression Interval (I_f). The number of aircraft operating hours between scheduled SPADE inspections is known as the Utilization Interval (U). The cumulative detection probability (P_{4c}) for SPADE is greater that its instantaneous value (P_{4i}) because during the failure progression interval there are several chances (I_f/U) for finding the defect, and only one detection is required to remove the failing component from service. The mathematical relationship between the cumulative probability of detecting an ongoing failure and these other diagnostic parameters is:

$$P_{4c} = 1- (1 -P_{4i})^{I_f/U}$$

Given this relationship and the experimental values for P_{4i}, it remains to estimate the failure progression interval, I_f, for bearings, and to select a SPADE Utilization Interval (U) that yields a satisfactory cumulative probability of fault detection. Of the twenty-eight (28) bearings used for implant testing during this and preceding Army diagnostic test programs, none have shown evidence of significant failure progression. Of these same bearings, eleven have been operated for times in excess of 100 hours and three in excess of 200 hours with a maximum spalled bearing operating time of just over 290 hours. Figure 1 shows SPADE's cumulative probability of fault detection as a function of its utilization interval. The curves in this Figure represent a range of instantaneous fault detection probabilities which "bracket" the results of testing during the Contractor Evaluation of SPADE. The important message from this Figure is that even for the worst case estimate of SPADE accuracy, a high cumulative probability of fault detection can be achieved with a 25 hour SPADE inspection interval. For example an accuracy of $P_{4i} = .45$ would indicate a cumulative probability of fault detection in excess of 99% at a 25 hour inspection interval and better than 90% at a 50 hour interval. In addition, any increase of the failure progression interval above 200 hours will result in an increase in the cumulative probability of fault detection.

The other side of the coin, of course, is the false indication rate that can be expected when employing the same limits that are associated with the detection accuracy just discussed. The caution and remove indication limits in SPADE are set at the mean plus 2-sigma (m + 2) and mean plus 3-sigma (m + 3) values respectively of all the confirmed baseline data accumulated for four (4) UH-1H aircraft during the Contractor Evaluation. Assuming a normal distribution of measurements, this should result in an instantaneous probability of false removal indication (P_{2i}) of .0027. The cumulative probability of false removal indication (P_{2c}) would then be the product of the number of SPADE measurements times (P_{2i}). Over one hundred SPADE measurements of baseline components were made during the Contractor Evaluation but no removal limit exceedances were observed. This record tends to confirm that P_{2i} for SPADE is .0027 or less. The Mean Time Between Removals due to false indications or ($MTBR_{fi}$) for each drivetrain component monitored by SPADE can be calculated from the equation:

$$MTBR_{fi} = \frac{\text{SPADE UTILIATION INTERVAL}}{\text{No. of sensors on component X } P_{2i}}$$

Table I lists the $MTBR_{fi}$ and corresponding false removal rate for each aircraft component at two SPADE Utilization Intervals (U=25 hr & U=50 hr). This Table also summarizes false removal rates for the total UH-1H drivetrain and the gearboxes vs. tail rotor driveshaft hangar bearings as separate component classes. It is important to note from this Table that even for a 25 flight hour SPADE Utilization Interval, the false removal rate is only slightly over one removal per thousand aircraft flight hours.

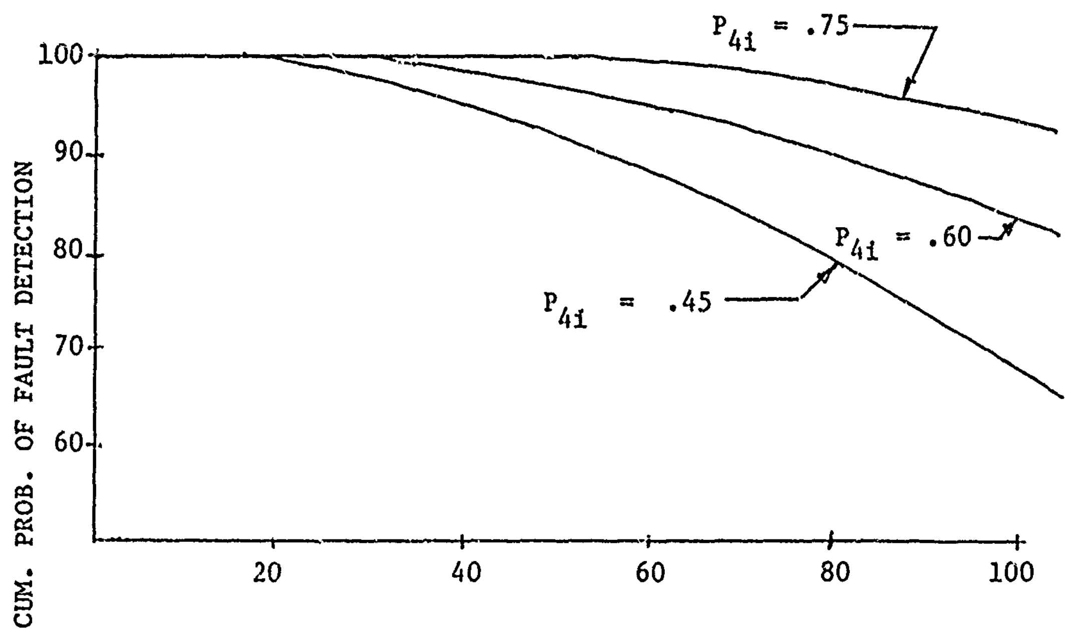
Conclusion: In summary then, even a pessimistic assessment of SPADE Contractor Evaluation test results indicates a high fault detection capability and a false removal rate of one per thousand flight hours. This accuracy exceeds the design requirements of 90% fault detection capability and 2 false removals per thousand flight hours.

AIRCRAFT COMPONENT	$MTBR_{fi}$ - Flt Hr		False Removals/1000 Flt Hr	
	U = 25	U = 50	U = 25	U = 50
Main Transmission	3086	6173	.324	.162
42 Gearbox	4630	9259	.216	.108
90 Gearbox	9259	18519	.108	.054
Hangar Bearings(4)	2315	4630	.432	.216
TOTAL DRIVETRAIN	926	1852	1.080	.540

U - SPADE UTILIZATION INTERVAL

SPADE CAUSED FALSE REMOVAL RATES

TABLE I



CUMULATIVE FAULT DETECTION CAPABILITY VERSUS SPADE UTILIZATION INTERVAL

FIGURE I

T700 Engine

The T700-GE-700 engine condition monitoring and diagnostic program consists of development and evaluation of:

On-engine sensors and components.
Off-engine monitoring equipment.
Diagnostic procedures.
Signal limit values.

The general objective was to permit an evaluation of condition monitoring concepts during the engine development for eventual selection of items suitable for the Black Hawk and AAH applications.

Several basic conclusions can be listed as a result of the study:

a. Overall engine health deterioration with use occurs in the areas of performance, lube systems and hot section.

b. These areas may be adequately monitored in the aircraft installation by:

(1) A Health Indication Test (H.I.T.) technique for power loss.

(2) A desensitized Chip Detector and lube filter Δ P signals.

(3) The improved T700 Engine History Recorder, supplemented by borescope provisions for hot section deterioration.

c. Mechanical and electrical failures will occur for which no deterioration signal is obtainable. These failures, of a sudden nature, can only be minimized by the adequacy of design execution, and the quality of manufacture, installation and maintenance.

The engine history recorder has proven to be useful for accumulating engine use data. The four parameters selected are:

a. A time-temperature index counter.

b. Elapsed time counter for engine operating hours.

c. A full cycle counter (LCF) for engine gas generator speed excursions from start to above 95%.

d. A partial cycle counter for gas generator speed excursions from 86% to 95% which represents excursions from flight idle to maximum continuous power.

It appears that it would also be worthwhile to develop a diagnostic connector and a quantative or rate-sensing chip detector.

Debris Analysis Development

An advanced helicopter oil-wetted component debris discriminating and filtration system is being developed by the Applied Technology Laboratory, US Army Research and Technology Laboratories (AVRADCOM) for the UH-1 and AH-1 helicopters with a potential use for all helicopters.

The system is designed to reduce the high rate of false chip indications and help reduce no-fault removals of oil-wetted components while improving component life and extending the useful life of the lubricating oil.

The flight evaluation of the system is being conducted at Fort Rucker, AL. The test aircraft have been modified with high-efficiency, three-micron oil filters on the engine and transmission and full flow-through, burn-off chip detectors. The 42- and 90-degree gearboxes which do not have circulating oil systems are equipped with splash-type, burn-off chip detectors.

The test and control aircraft will be flown without oil changes. Oil samples from the engine and transmission will be taken at 50-hour intervals for physical property analysis to insure that the oil remains within government specification. The minute particles peculiar to chip detectors that are separated after such analysis will be microscopically analyzed. This analysis, then, will be used to develop criteria that will lead to a reduction in no-fault removals. To aid in the formulation of removal criteria, all components that are removed for oil-wetted problems or high time will be subjected to a teardown analysis.

Projected benefits are 25 percent improvement in mission reliability, 10 percent increase in the time between component repairs, 1,000 percent increase in oil life and 100 percent increase in bearing life, an annual savings of approximately $4 million could result from the adoption of this program for the UH-1 and AH-1 helicopter fleet alone.

The most promising of the long range efforts is the Assessment of Augmented Electronic Fuel Controls for Modular Engine Diagnostics and Condition Monitoring by the General Electric Company under contract with AVRADCOM ATL.

The object of this particular effort was to establish the requirements and to define the approaches to be used to include condition monitoring and on-condition maintenance features in the design of advanced electronic control systems for helicopter turboshaft engines. Although the investigation is considered to be generic in nature, the General Electric T700 gas turbine engine was used to derive real world experience and to evaluate applicability to an existing Army helicopter gas turbine engine. The T700 engine is being employed on the Army's UH-60A BLACK HAWK helicopter (Sikorsky) and on the advanced attack helicopter (AAH) under development by Hughes Helicopters.

Fault isolation to the module and line replaceable unit (LRU) level by means of a Diagnostic and Condition Monitoring (D&CM) System integrated with a Full-Authority Digital Electronic Control (FADEC) is evaluated in this study. A preliminary assessment of the D&CM system parameters required for performing the diagnostic functions on the current T700 engine is also included in the study.

A T700 functional baseline FADEC control design was established which contained approximately 70% of the parameters planned for diagnostics and condition monitoring. An integral part of the GE FADEC system is Failure Indication and Corretive Action (FICA), based on extended Kalman-Bucy filtering techniques. An important part of this study was to adapt FICA to a turboshaft engine. This effort showed by computer simulation that the system could detect single and multiple control sensor failures, and could make corrections which would permit continued satisfactory engine operation by the use of simulated control sensor signals estimated by FICA. Indication of failed sensors by FICA and indication of computer failures through self-test provide inherently significant D&CM capability. The FICA system also calculates intermediate engine parameters, such as T3 and T4.1, allowing more complex hot part life calculations.

General Electric's (GE's) experience with the T700-GE-700 turboshaft engine and other engine condition monitoring activities was used to determine the diagnostic functions desired. Fault isolation to the LRU and module levels is discussed and preliminary lists of parameters required for implementation on both FADEC and non-FADEC-equipped engines are provided. Further study and analysis, however, is necessary to verify the system effectiveness.

Integration of the FADEC and D&CM systems at the outset of the control design provides the potential for maintenance payoffs associated with D&CM at reduced development and procurement cost. It is concluded in this report that:

a. The FADEC system can inherently accomplish the D&CM functions of engine history calculations, detection of most control sensor failures, and detection of some control system failures.

b. The FADEC system should accomplish all D&CM signal processing except vibrations.

c. D&CM functions such as a HIT check, tracking oil pressure and detection of overtemperature, filter bypass, and chip detection indications should be integrated into FADEC.

If the momentum of this program is to be maintained, the following steps must be taken in the near future:

a. A detailed study (to be followed by a test phase) of a D&CM system to achieve the specific goal of fault isolation to the Module and LRU level for a T700 Engine on-the-wing in a cost effective manner.

b. A digital, engine-mounted history recorder containing important basic elements should be designed, fabricated, and engine tested to demonstrate integration of engine history and health in a unit using FADEC technology.

c. A study should be initiated to increase FADEC system ability to detect and provide corrective action for control system failures not detected by FICA or self-test, thereby increasing D&CM capability.

SUMMARY

The current status of propulsion monitoring techniques was reviewed and found to be adequate to protect life and property but unnecessarily expensive. Several development programs were reviewed most of which should be completed during the next three to five years. The major problems at this point are finding equipment that is both cost-effective and affordable. A standard approach to determining cost-effectiveness of various systems is needed. The final task will be to standardize across various aircraft systems to lower development costs and reduce the proliferation of test equipment in the field.

ULAIDS STATUS

BY

D. WATTERS

NATC PAX RIVER MD

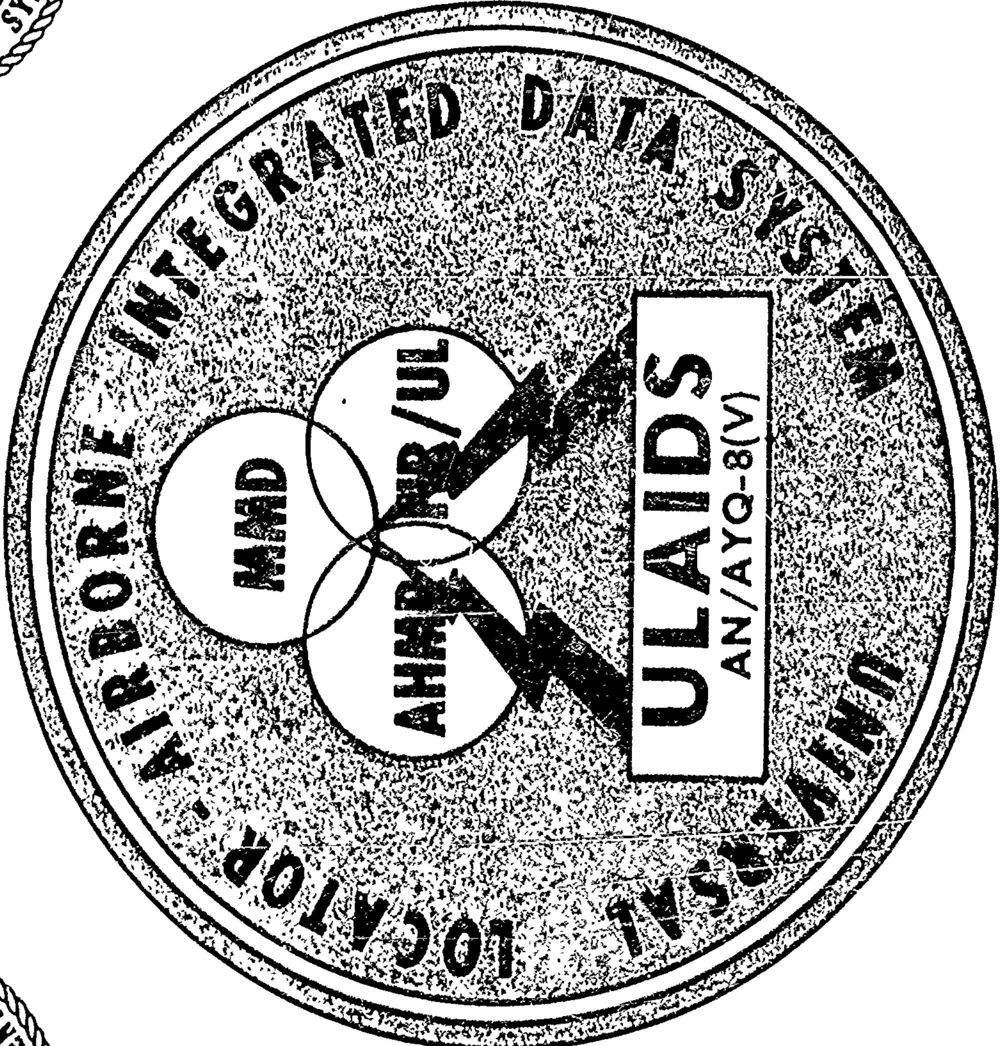
AV 356-4673

ABSTRACT

Universal Locator-Airborne Integrated Data System (ULAIDS)

The goal of this system is to demonstrate the integration of state-of-the-art airborne system monitoring concepts into a standardized micro-processing/multiplexing system adaptable to all types of aircraft.

The prototype combines off-the-shelf and new design hardware using the A-7E as a testbed. It uses existing aircraft sensors including IECMS sensor harness. The system currently exceeds the production goals for system weight and power. The contractors for this system are the same as EDS and they have experienced the same problems as the AF including a large dollar overrun and schedule slip.


UNIVERSAL LOCATOR · AIRBORNE INTEGRATED DATA SYSTEM
MMD
AHMR
FR/UL
ULAIDS
AN/AYQ-8(V)

PROJECT ULAIDS

- ADVANCES IN MICROPROCESSING, MICROELECTRONIC MEMORIES, MULTIPLEXING, AND DATA BUS MANAGEMENT TECHNIQUES HAVE MADE AIRCRAFT ON BOARD TOTAL SYSTEM MONITORING AND MAINTENANCE RECORDING FEASIBLE.
- INTEGRATING MONITORING AND RECORDING FUNCTIONS INTO A FLEXIBLE SINGLE-SYSTEM CONCEPT PROVIDES A STANDARDIZED AND COST EFFECTIVE AVENUE FOR FUTURE WEAPON SYSTEM PROCUREMENT APPLICATIONS.

TID A 3749v

ULAIDS SYSTEM GOALS

INCREASE

- FLIGHT SAFETY
- MISSION EFFECTIVENESS
- AIRCRAFT AVAILABILITY
- LOGISTICS EFFICIENCY
- COST EFFECTIVENESS

TID A 520v

PROGRAM DESIGN GOALS

DEMONSTRATE THE INTEGRATION OF STATE-OF-THE-ART AIRBORNE SYSTEM MONITORING CONCEPTS INTO A STANDARIZED MICROPROCESSING/MULTIPLEXING SYSTEM ADAPTABLE TO ALL TYPES OF AIRCRAFT.

PROCUREMENT DOCUMENTATION: *DEVELOP COMPLETE GOVERNMENT PROCUREMENT SPECIFICATIONS AND DRAWINGS TO PROVIDE FOR FUTURE ULAIDS (OR SUBSYSTEMS THEREOF) PROCUREMENTS FOR MILITARY AIRCRAFT

*ALL PROTOTYPE HARDWARE, SOFTWARE AND SYSTEM DOCUMENTATION ARE CONTRACT DELIVERABLES.

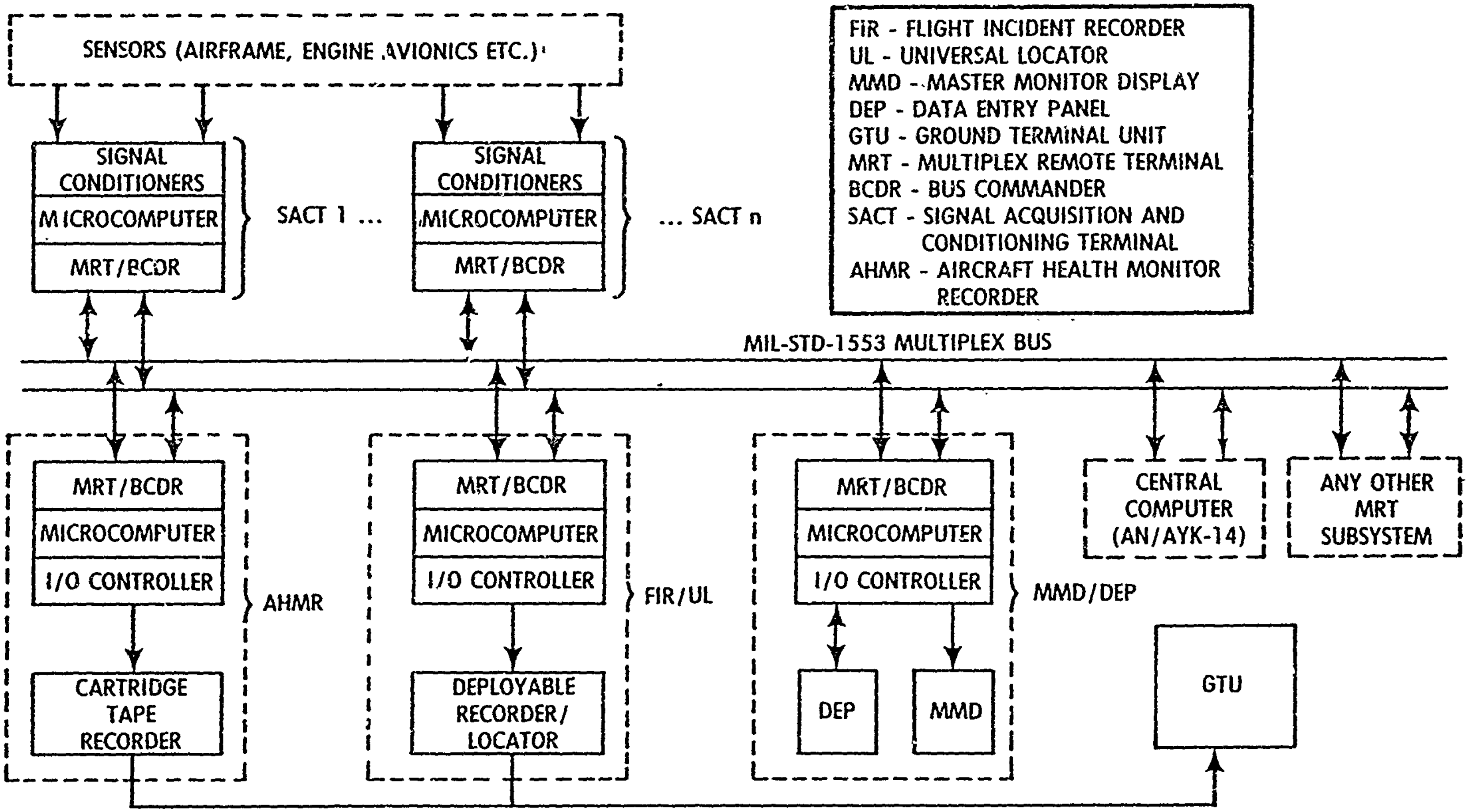
TID A 3744v

ULAIDS PROTOTYPE

- COMBINED OFF-THE-SHELF AND NEW DESIGN HARDWARE
- A-7E TESTBED
- USES EXISTING AIRCRAFT SENSORS, INCLUDING IECMS SENSOR HARNESS
- SYSTEM WEIGHT: 131 LBS (HIGH SIDE ESTIMATE)
  - PRODUCTION GOAL OF 90 LBS
- SYSTEM POWER: 488 WATTS (HIGH SIDE ESTIMATE)
  - PRODUCTION GOAL OF 330 WATTS

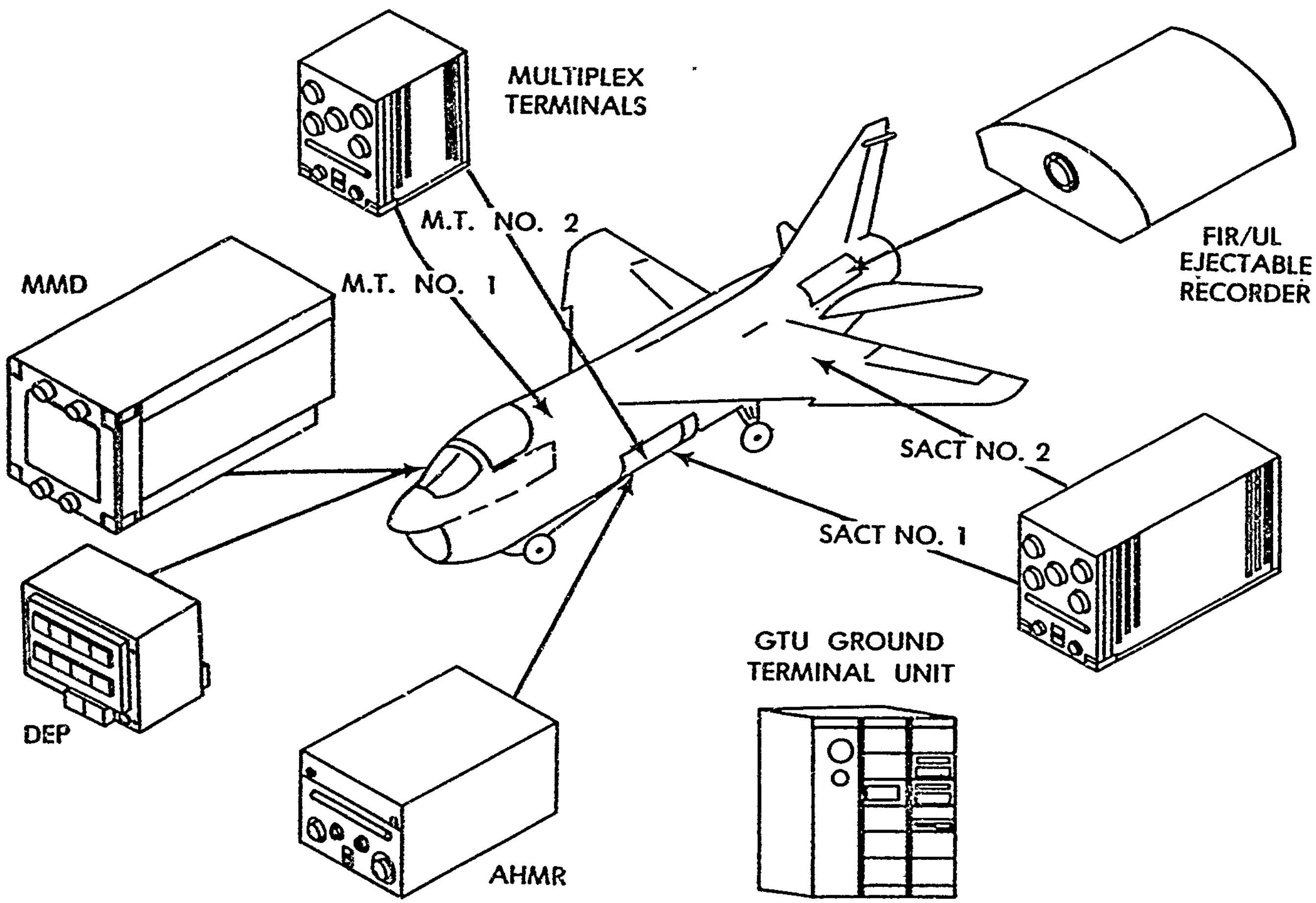
TID A 3750v

ULAIDS FUNCTIONAL DIAGRAM, DISTRIBUTED MICROCOMPUTER SYSTEM



TID A 162v

ULAIDS SYSTEM AN/AYQ-8(V)(XN-1)
A7E AIRCRAFT INSTALLATION



TID A 3285v

ULAIDS SOFTWARE DESIGN

- MODULAR AND FLEXIBLE
- STANDARDIZED EXECUTIVE SOFTWARE THAT CAN BE INDEPENDENTLY CONFIGURED FOR EACH SUBSYSTEM DISTRIBUTED MICROCOMPUTER
- MODULAR EXECUTIVE SOFTWARE DESIGN THAT IS TABLE DRIVEN WHEREVER POSSIBLE ALLOWING MAXIMUM FLEXIBILITY TO INCLUDE OR EXCLUDE FEATURES AS REQUIRED
- APPLICATION SOFTWARE RUNS AS INDEPENDENT TASKS, SUBORDINATE TO AND SUPERVISED BY THE EXECUTIVE SOFTWARE. SUBSYSTEM TASK LISTS ARE GENERATED AT CONFIGURATION (ASSEMBLY TIME) AND ARE EASILY MODIFIED TO ADD OR DROP TASKS.

TID A 4871v

ULAIDS SENSOR/PARAMETER SIGNAL CAPACITY

SIGNAL TYPE	TYPICAL MIN. CAPACITY	TYPICAL MAX. CAPACITY
DISCRETE (0 & 5 VDC LEVELS)	4	12
DISCRETE (0 & 28 VDC LEVELS)	24	72
DISCRETE (CLOSURE TO GND)	8	24
PULSE COUNTER/TORQUER (0 & 5 VDC LEVELS)	1	2
AC ANALOG (DIFFERENTIAL)	10	10
DC ANALOG (DIFFERENTIAL)	14	14
SYNCRO	8	16
SERIAL DIGITAL	2	2
MAGNESYN	4	4
TACHOMETER	4	4
FREQUENCY	4	4
THERMOCOUPLE	3	3
RESISTANCE THERMOMETER	4	4
RESOLVER	8	8
PIEZOELECTRIC ACCELEROMETER	8	8
TOTAL PER SACT	106	187
TOTAL (TWO SACTS)	212	374

TID A 4872v

AIRBORNE/REAL TIME

- PARAMETER LIMIT EXCEEDANCE OR FAILURE - AUTOMATIC ALERT DISPLAY AND RECORD
- DEGRADING TRENDS - AUTOMATIC ADVISORY DISPLAY AND RECORD
- EMERGENCY PROCEDURES - AUTOMATIC ALERT DISPLAY
- SELECTED CURRENT PARAMETERS (GAUGE SUB-STITUTION) - AUTOMATIC OR CALLUP DISPLAY
- FLIGHT LINE MAINTENANCE - CALLUP DISPLAY (HISTORY OF PARAMETER LIMIT EXCEEDANCE WITH FAULT ISOLATION)

TID A 3721v

SAFETY

- CRASH ANALYSIS - FLIGHT INCIDENT RECORDER
- CRASH POSITION LOCATION - UNIVERSAL LOCATOR
- SYSTEMS SAFETY - HEALTH MONITORING

TID A 3743v

POST FLIGHT ANALYSIS

- IN DEPTH MAINTENANCE DIAGNOSTICS
- PERFORMANCE TRENDING
  - TOTAL SYSTEM EFFICIENCY OPTIMIZATION THROUGH SUB-SYSTEM TRIMMING/ADJUSTMENT — ENGINE FUEL CONTROL, DRAG, LANDING PERFORMANCE
  - SINGLE POINT DEGRADATION THROUGH SUB-SYSTEM PERFORMANCE MONITORING AND EVALUATION - ACCURACY, CONSISTANCY, TIMELINESS
  - PILOT PERFORMANCE/TRAINING
- FORECASTING
  - FAILURE PROJECTION & REPLACEMENT
  - ELIMINATE PHASE AND FORCED REMOVAL MAINTENANCE CONCEPTS

TID A 3742v

RELATED PROGRAMS

- ADVANCED INTEGRATED DISPLAY SYSTEMS (AIDS) — NAVY
- DIGITAL AVIONICS INFORMATION SYSTEMS (DAIS) — AIR FORCE
- INTEGRATED ENGINE INSTRUMENT SYSTEM (IEIS) — NAVY
- GENERAL PURPOSE MULTIPLEXING SYSTEM (GPMS) — NAVY
- INFLIGHT ENGINE CONDITION MONITORING SYSTEM (IECMS) — NAVY
- AUTOMATIC INSPECTION DIAGNOSTIC AND PROGNOSTIC SYSTEM (AIDAPS) — ARMY
- BASIC AVIONIC SUBSYSTEM INTEGRATION CONCEPT (BASIC LAB) — NAVY

TID A 3746v

ADVANTAGES

- QUANTUM IMPROVEMENTS IN OVERALL AIRCRAFT
  - MISSION EFFECTIVENESS
    - STANDARDIZED REAL-TIME SYSTEM MANAGEMENT AND BACKUP LOGIC
    - INCREASED SUCCESS CONFIDENCE (FROM PROJECTION AND TRENDING CAPABILITIES)
  - SAFETY
    - OVERALL SYSTEM SAFETY
    - UNIVERSAL LOCATOR/INCIDENT ANALYSIS
  - RELIABILITY
    - CONTINUOUS SYSTEM HEALTH STATUS
    - SYSTEM CONFIDENCE IN ABSENCE OF PROJECTED FAILURES OR ADVERSE TRENDS
  - ILS & MAINTAINABILITY
    - ACCURATE AND TIMELY MAINTENANCE ACTION
    - FAILURE PROJECTION/SYSTEM TRENDING
      - LOWER MAINTENANCE HOURS
      - LOWER MATERIAL COSTS

TID A 3748v

SAVINGS THROUGH SYSTEM MONITORING

- C-5
  - $5.65 MILLION YEARLY SAVINGS
  - COST: $.79 MILLION NON-RECURRING
    $1.9 MILLION ANNUAL
- TWA ACTUAL ANNUAL SAVINGS (30 L-1011 & 10 B-747)
  - FUEL $343,000
  - ENGINES $428,000
  - HYDRAULICS $130,000
  - ELECTRONICS $ 9,000
- TWA PROJECTED SAVINGS (30 WIDE-BODY AIRCRAFT)
  - $9M INITIAL INVESTMENT
  - $1M ANNUAL RECURRING COST
  - $6.5M ANNUAL SAVINGS BEYOND 1ST YEAR
  - PAYBACK IN 2.25 YEARS (INCLUDING RECURRING COSTS)

TID A 3738v

POTENTIAL
NAVY SAVING AREAS

AIRCRAFT INCIDENTS (MATERIAL FAILURE PRECIPITATED)	$100 MILLION YEARLY
MAINTENANCE:	
• NON-DEFECTIVE REPAIR (A-799 RATE)	$10 MILLION YEARLY
• SCHEDULED MAINTENANCE (PHASE)	
• SPARE PARTS LOGISTICS	
PROCUREMENT:	
• ULAIDS VS PECULIAR DESIGN FOR EACH NEW AIRCRAFT	SAVINGS TO BE DETERMINED

TID A 3747v

NASA ENGINE DIAGNOSTIC PROGRAM

BY

E. SZANCA

NASA LEWIS RESEARCH CENTER
CLEVELAND OHIO

33-4000 x6979

ABSTRACT

Diagnostics are identifying sources of engine performace deterioration. The NASA approach is to gathering existing data for establishing trends. New data will be gathered to fill in the gaps. The short term data (100 flights) will b› augmented by long term data to identify deterioration from corrosion and erosion and outer air seals. The task includes the determination of sensitivity of the performance of specific components to deteriorated parts and establishing statistical trends, analytical models and design criteria for current and future engines. There was emphasis on the fact that the instrument system introduces more error than engine variances. The Naval Air Rework representative commented that their instrument problems are calibration and drift.

There were comments on mathematical juggling of instrument readings to derive useful values. Further comments indicated no confidence in the mathematics of random samples.

NASA LEWIS RESEARCH CENTER

ENGINE COMPONENT IMPROVEMENT OBJECTIVES

PERFORMANCE IMPROVEMENT

- DEVELOP FUEL SAVING COMPONENT TECHNOLOGY FOR INTRODUCTION INTO CURRENT ENGINES (JT8D, JT9D, CF6) BY 1980-82

ENGINE DIAGNOSTICS

- IDENTIFY SOURCES OF PERFORMANCE DETERIORATION OF CURRENT ENGINES (JT9D, CF6) & DEVELOP CRITERIA FOR MINIMIZING SUCH LOSSES

WITHOUT PENALIZING SAFETY, RELIABILITY, OR ENVIRONMENTAL IMPACT

ENGINE COMPONENT IMPROVEMENT

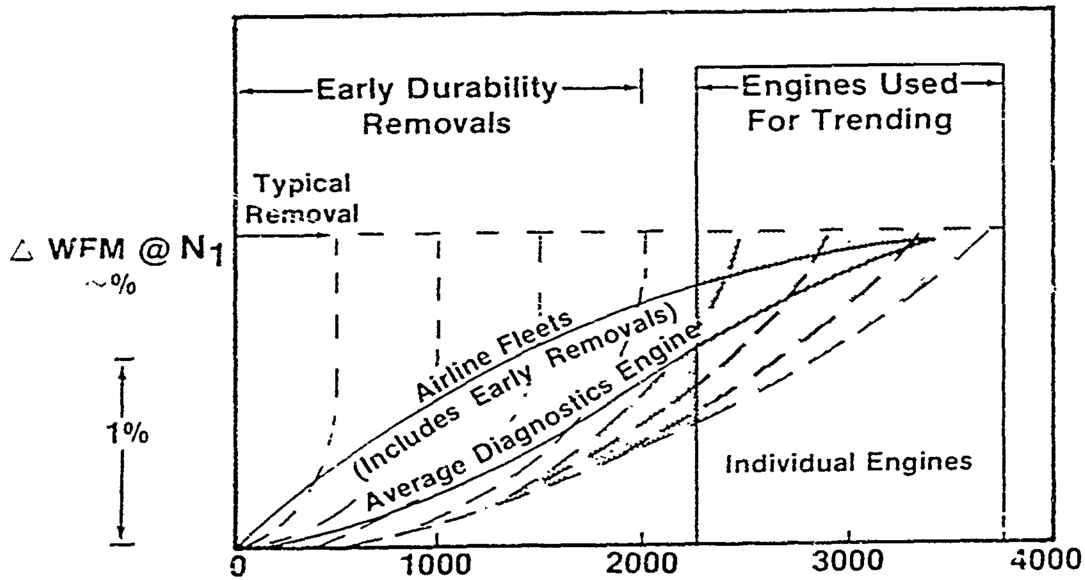
ENGINE DIAGNOSTICS

APPROACH

- GATHER EXISTING DATA TO ESTABLISH HISTORICAL TRENDS OF ENGINE PERFORMANCE DETERIORATION
- GATHER NEW DATA FROM IN-SERVICE ENGINES
- ASSESS CAUSES OF SHORT-TERM DEGRADATION THROUGH SYSTEMATIC, SPECIALIZED TESTING OF NEW OR LOW-TIME ENGINES
- ASSESS CAUSES OF LONG-TERM DEGRADATION THROUGH SYSTEMATIC, SPECIALIZED TESTING OF HIGH-TIME ENGINES
- DETERMINE SENSITIVITY OF PERFORMANCE OF SPECIFIC COMPONENTS TO DETERIORATED PARTS
- ESTABLISH STATISTICAL TRENDS, ANALYTICAL MODELS, & DESIGN CRITERIA FOR CURRENT & FUTURE ENGINES

Deterioration Curve Shape

Refurbished Engines — All Airlines

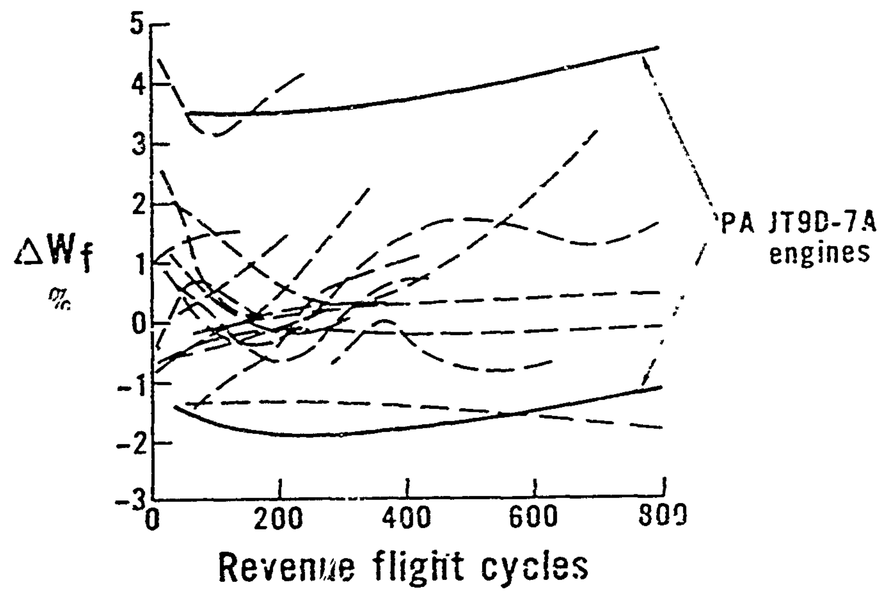


- Shape of Deterioration Trend Dependent on Engine Sample

FLIGHT DATA RESULTS

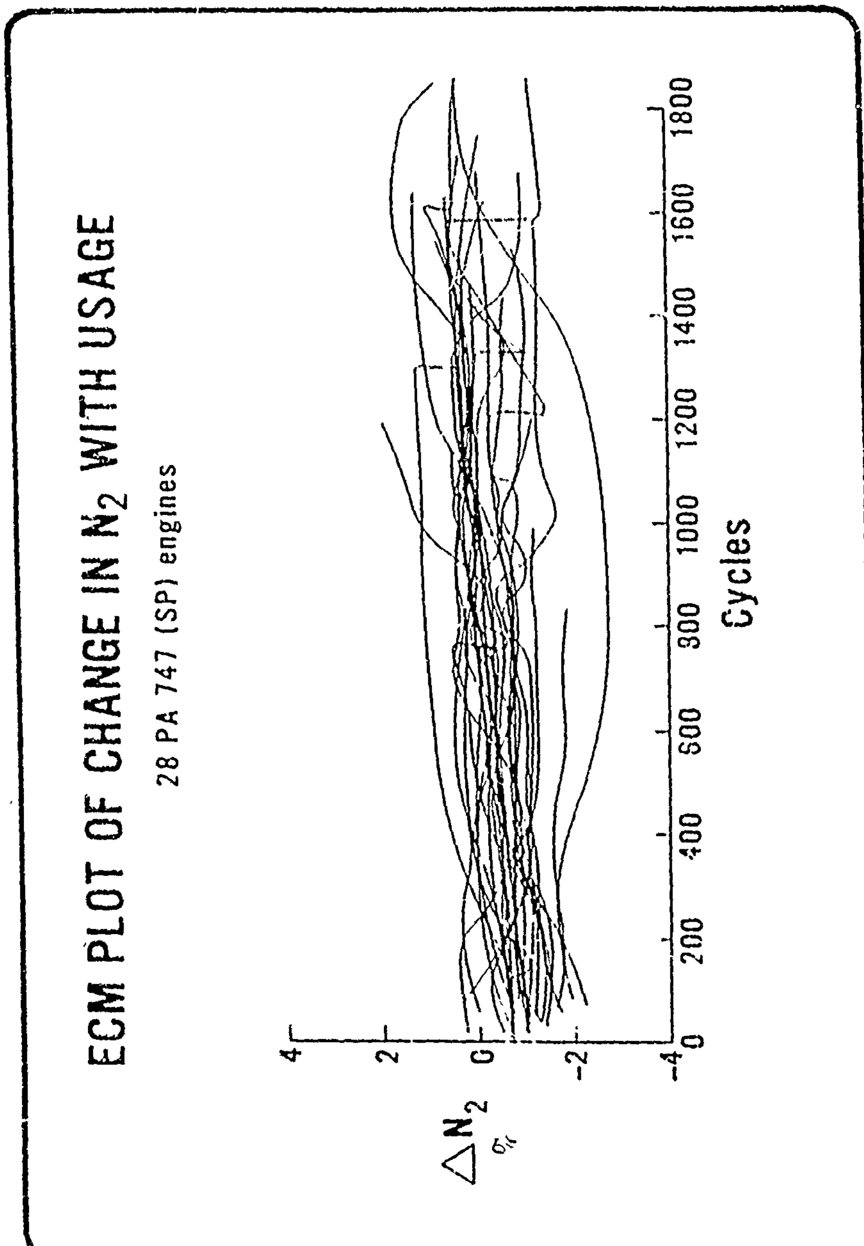
- Individual engine trends exhibit considerable scatter, making analysis difficult
- Insufficient flight deck instrumentation for modular analysis
- Flight data useful only in establishing gross trends in performance
- Agreement between individual engine inflight calibration and ECM data suggests erratic trends caused by airplane systems rather than data taking

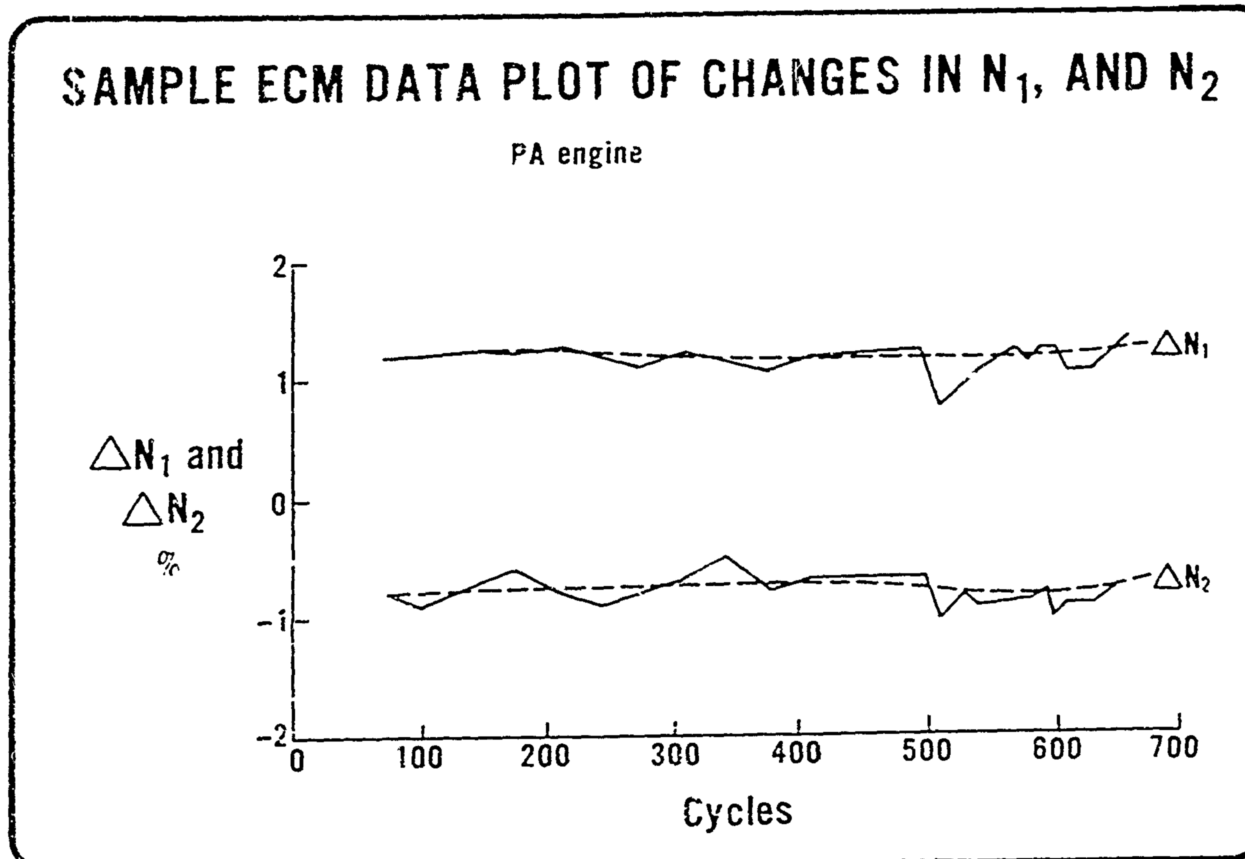
ORIGINAL vs SPARE ENGINE PERFORMANCE DETERIORATION



Spare engines

Air India	695607
China Air	695724
	695725
	695726
Iran Air	689561
Iraqi Air	689526
	689529
	689556
NWA	686125
	686174
Seaboard	689158
	689161
Singapore	695735
	695757
SAA	689534
	689570


ECM PLOT OF CHANGE IN N_2 WITH USAGE
28 PA 747 (SP) engines
ΔN_2 %
4
2
0
-2
-4
0
200
400
600
800
1000
1200
1400
1600
1800
Cycles


SAMPLE ECM DATA PLOT OF CHANGES IN N_1, AND N_2
PA engine
ΔN_1 and ΔN_2 %
2
1
0
-1
-2
0
100
200
300
400
500
600
700
Cycles
ΔN_1
ΔN_2

SAC ENGINE CONDITIONING MONITORING PROGRAM (ECMP)

BY

SMSGT T. STRAUSS, SAC

SAC/LGMS

AV 271-5347

HIGHLIGHTS

SAC Method of Engine Condition Monitoring

SAC flight crews manually record during specific B-52 and KC-135 flight conditions, N_2, RPM, EGT, Fuel flow, throttle position and vibration. Ground crews record oil consumption and correct the inflight data to provide an engine signature. Deviations for established signatures identify engine or instrument problems. The method has produced cost savings in excess of \$50 million and reduced the inflight shut down rate by 50%.

SMS Strauss commented that the problems are three instruments to one engine problem. The current interpretation procedure uses the cycle deck or gas generator curve limits as normal operation bands, not Go or No Go. Operation outside the bands places the engine in watch status where extra attention is given to find the cause of the unusual indication. The inflight data from the Offutt based E-4As is sent to General Electric (GE) for monitoring and analysis.

The FB111A aircraft effort has been suspended because of the low time between engine removal for FAN enhancement and combustion case repair.

Future plans include: reduction of administrative and manual work; use MIMICS/CEMS to produce trend plots; rework the FB111 program.

SYNOPSIS OF THE SAC ENGINE CONDITIONING

MONITORING PROGRAM (ECMP)

1. SAC's ECMP is a combination of American Airlines - manual approach, TWA - computer based, and P&WA procedures; all modified to fit the SAC maintenance concept.

2. ECMP is based on the six engine parameters available to the flight crew. (N2 RPM - nearest .1%; EGT - nearest 5°C; fuel flow - nearest 100 PPH; throttle position at NRT; vibration - subjective evaluation by crew member; oil consumption - quarts per hour from after flight servicing.) N2 RPM is the most sensitive parameter to engine hot section deterioration. N1 RPM would be invaluable in conjunction with N2 but is not available. EGT is also good but must be used with RPM. Fuel flow is not much value because of poor instrument accuracy but can be used with RPM and EGT for confirmation of a problem. Crews take data readings once per flight by advancing inboard engines or pods to NRT and reducing outboard engines or pods to maintain mach and altitude. Parameters are recorded and the process is reversed to get readings on the outboard engines or pods. Crews have been able to obtain data on approximately 93% of all flights. The ground crew reports oil servicing after each flight and the engine monitoring team uses it to trend oil consumption.

3. The raw inflight data gathered by the flight crew is corrected to a standard using an Hewlett-Packard (HP-97) programmable calculator. Our procedure prohibits correction to the international standard day, therefore SAC propulsion personnel correct to standard atmospheric conditions established for each type of aircraft and its typical flight profile. For example, the standard used for all B-52's is 30,000 ft., .75 mach,

-20° OAT. All inflight data is corrected or "normalized" to these conditions. Use of the HP-97 calculator, in lieu of the earlier manual computations, has reduced data scatter by 15%. The "normalized" data is plotted on a performance evaluation work sheet to create (graph) a unique engine signature. Any significant deviation in that plot indicates some type of problem. In most cases it is an instrument system problem or a bleed air discrepancy. However, if investigation of these does not detect the cause of the deviation it could mean internal damage to the engine hot section. Depending on the severity of the suspected problem, work may be delayed until it can be done on a scheduled basis such as during phase inspection. If an attempted fix does not bring the trend back to its original position continued investigation is needed. The last resort is to drop the engine for in shop work.

4. The ECMP compares the engine against its most recent history to determine if a problem exists and avoids the use of set limits except as a general guideline. When going into the program we first relied on typical "normal" operation bands as reference points for maintenance action because the engines had many previously unnoticed problems. Now, with a stable program we can disregard engines that consistently plot outside the normal band without a trend deviation.

a. The specifics of the program are contained in a SAC regulation which explains how data is taken and how it is corrected for plotting. It also contains instructions for converting ground test cell and trim runs to the flight conditions. The test cell data is used to establish a baseline, as we consider this to be the most accurate reference point for initiating an engine signature. We have used a SAC regulation to implement and administer

ECMP for several reasons. First, many aspects of the program require a subjective evaluation and a tech order format is not the ideal medium. Secondly, as we learn more through the program it is easier and less expensive to change. Finally, the AFLC depot is hesitant to formally institute a program such as ours.

5. Fleetwide testing of all SAC EC/RC/KC-135 began in Dec 1976 and continued through Sep 1977. In Oct 1977 the -135 test program was converted to a standard operating procedure under SACR 66-22. The B-52D and B-52G test programs began in April 1977 and May 1977 respectively and were formally implemented under SACR 66-22 in Oct 1978. The B-52H test began Sep 77 and is continuing. We have a problem with some engines exceeding the EGT limit at NRT power. When this is resolved the B-52H program will be formalized. We implemented a test program on the TF30-P7 engine installed in our FB-111's but the test was unsuccessful. The test has been suspended for two reasons. The constant engine removals for TCTO's are not conducive to developing trends. The applied correction factors appear to be incorrect and cause excessive scatter in the trend plots. We have recalled all of the data for analyzation with the intention to resolve the problems and reinitiate the program.

6. The following are the results of the program since fleetwide implementation.

	-135	B-52D	B-52G	B-52H
Engines Removed for ECMP	427	66	220	13
Instrument Repairs (EPR, EGT, RPM, F/F)	2806	573	1785	749

	-135	B-52D	B-52G	B-52H
Engine Related Peripheral Equipment Repairs (Bleed air, oil, vibration)	1276	550	1072	232
Engine Failures Not Identified by ECMP	80*	**	**	**

* Only for the past FY

** Not recorded during test

a. These problems were detected by ECMP with no aircrew write-ups or scheduled maintenance inspection associated. Undoubtedly, some would have been detected had they been allowed to further deteriorate. Examples of damage found on engines removed for ECMP are combustion inner cone failure before it caused turbine shellout, or extreme bowing of first stage nozzle guide vanes prior to vane failure. Examples of instrument problems are failed EPR transducers that cause the engine to be overboosted, or EGT gauges that read low and cause unnoticed overtemperatures. Other engine repairs would be excessive bleed air leaks, bad bleed valve governors, or actuators which cause the engine to run hotter and faster than necessary to produce a given EPR. The engine failures not detected by ECMP are low in comparison to the other figures because this data was not accumulated during the test period.

7. Significant benefits are obtained from the simplified method used by SAC. Engine monitoring can be done without investing in expensive hardware. Several lessons have been learned.

a. The engine instrument systems cause the majority of the problems. Instrument failures occur about three times as often as actual engine problems. This is because of the age of the systems as well as the state of the art when they were first designed. The system tolerances are so great that they contribute significantly to the amount of variance in what can be considered a "normal" engine. This also makes direct comparisons between trim equipment and aircraft cockpit instruments difficult. If ECMP is adopted on older aircraft, be prepared for instrumentation problems.

b. Reduce the non-technical work as much as possible so that the experienced engine technician does not waste time and knowledge doing a job that anyone can do. Initially our program took a significant amount of time to retrieve the data from debriefing, correct it, and then plot it. Although this part can be done by the least knowledgeable people, the experienced technician is needed when the trend plot is analyzed. Unfortunately, the experienced technician must do some of the administrative work. Don't sacrifice the program by using individuals with limited technical qualifications!

c. Related to the previous is the need for the decision makers in the engine shops to be involved early in the program. It does absolutely no good for an engine monitoring team member to issue a work order if maintenance managers choose to ignore them and continue doing things the old way. This is probably the most difficult problem to overcome. Positive results from the program are needed early to get their attention and confidence.

d. There is also a need to understand a "normal" engine. Some engines run hotter, cooler, slower or faster. Compare the engine only to its past performance. When a monitoring program is started, it is necessary to use a "normal" operation band to assess the internal condition of an engine because so many engines have undetected problems. As understanding of the program progresses and the condition of the fleet engines improve, the emphasis on how a "normal" engine trend should look is not nearly as important.

e. Flight crews supply the data source for the entire program. It is very important that they understand how engine monitoring benefits them as they are not excited about filling out data forms. The best way to do this is to show them the failed pieces of an engine hot section removed for ECMP and explain what could have happened if the engine had flown longer. Amazingly, the amount and accuracy of inflight data will improve.

f. Finally, expect an initial increase in workload for both engine and instrument shop personnel and some increase in parts cost until existing problems are detected and corrected. Once this initial surge is over, the workload will gradually decrease and stabilize. Consider this the down payment for more reliable, safer engines.

8. In the future, we hope to reduce the administrative workload by using the MMICS/CEMS computer to prepare our engine trend plots. We foresee the day when the debriefer will input the inflight data in the computer to produce the plot. The only thing required of the engine monitors will be to analyze the trend after each flight to see if any problems are developing.

9. In summary, the SAC simplified ECMP is not a panacea to predict all or every type of engine failure. It was designed for specific

purposes to be used by engine mechanics who may or may not understand gas path performance analysis. It has helped to reduce inflight shutdowns, improve engine reliability by early problem detection, reduce secondary damage, and is one step further toward on-condition maintenance.

OPR: HQ SAC/LGMS
Offutt AFB, NE
AV: 271-5347/4958

UNCLASSIFIED

<u>EFFECTIVE USE OF MANAGEMENT INFORMATION</u>

A. DEFINE INFORMATION SYSTEM (REPRESENTATIVE, USEFUL, ACCURATE).

B. ESTABLISH A REFERENCE CONDITION (PLAN/GOAL/OBJECTIVE).

<u>CROSSCHECK</u>

C. <u>OBSERVE</u> (CAPTURE INFORMATION RELATED TO ACTUAL CONDITION)

D. <u>CORRECT</u> (NORMALIZE INFORMATION TO COMMON BASE).

<u>INTERPRET</u>

E. <u>COMPARE</u> (NORMALIZED INFORMATION COMPARED TO REFERENCE PRODUCES A QUANTIFIED DEVIATION/ERROR).

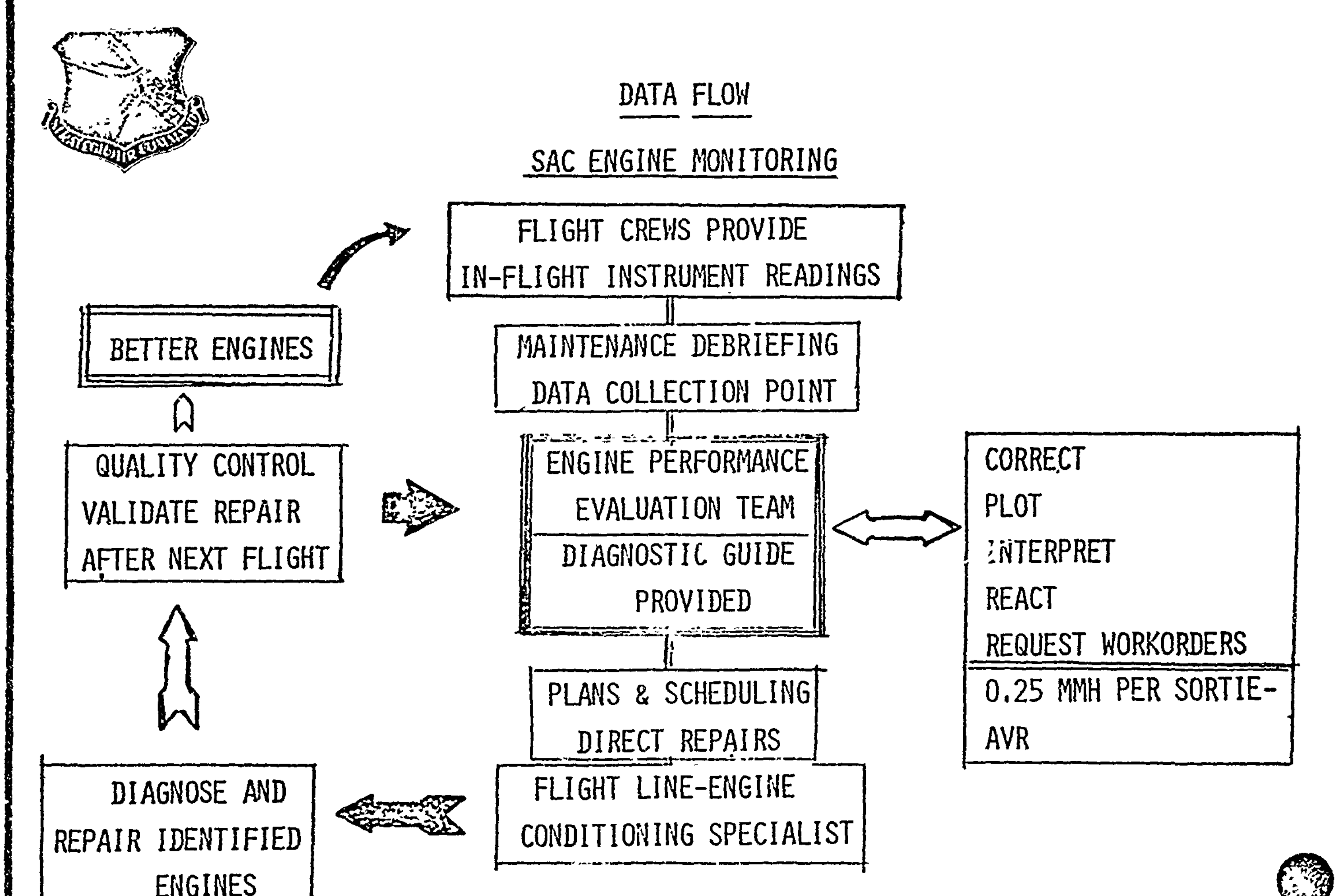
<u>CONTROL</u>

F. <u>CONTROL</u> (TAKE ACTION TO ELIMINATE DEVIATIONS).

G. <u>FEEDBACK</u> (REPEAT PROCESS, USE A FREQUENT SAMPLE INTERVAL, ESTABLISH REALTIME TRENDS - SEE RESULTS OF CONTROL).

UNCLASSIFIED

UNCLASSIFIED



UNCLASSIFIED

T38 EHMS

BY

SMSGT K. POBANZ

TAC/LGMS

AV 432-7571

HIGHLIGHTS

T-38 Engine Health Monitoring System (EHMS)

The twelve month evaluation at Holloman AFB was just completed Sep 78. The system totalled 1,963 engine flight hours. A 92% event detection rate was realized, with an event detection rate of 77% by EHMS only. This compares favorably to the rate of 20% from the earlier ATC evaluation. TAC personnel have a positive attitude towards this system, and have expressed interest to incorporate the system into their fleet with only a few improvements. An A-10/T-38 co-production decision is scheduled for Dec 79.

T-38 EHMS UPDATE

The TAC evaluation was initiated as a follow-on to the ATC evaluation completed in May 1977. The purpose was to evaluate the system in the more severe TAC flight environment. The evaluation involved five of the original nine ATC aircraft flying for 12 months in the lead-in fighter training program at Holloman AFB NM. Two of the aircraft were modified to T-38B configuration used for ground attack training. The T-38B has the capability of carrying a SUU-20 dispenser with six practice bombs and four rockets, or a mini-gun. The remaining three T-38A aircraft were flown in the air-to-air training role. The evaluation began in October 1977 and was concluded in September of this year. In addition to the more severe flight environments, this evaluation differed from the ATC evaluation in that it was accomplished with minimal on-site contractor support. Our objective was to keep it as much a blue suit operation as possible to determine the extent to which the system aided the average mechanic. On-site contractor support was used during the first two weeks of the program for training and thereafter was restricted to periodic visits for equipment repair.

During the 12 month evaluation, we accrued 1963 engine flight hours for an average of 16.3 hours per aircraft per month. This was somewhat less than we had planned to accrue (Goal 3000 EFH), but aircraft structural problems kept several of the aircraft grounded for a time. The results of the evaluation are as shown here. As during the ATC evaluation, the event detection rate was high. In this case, 92%. We are also encouraged by the low number of false alarms. The important point here is that none of these resulted in unnecessary maintenance. It was obvious from reviewing the data and talking to the aircrews that no problem had occurred. We also think that the number of out-of-scope incidents is within acceptable bounds. Again, we would like for this number to be zero, but from a practical standpoint its not feasible to try and detect everything. The number of no maintenance actions was somewhat alarming at first. This was something that rarely occurred during the ATC test and initially we didn't understand the cause. There were two types of these incidents. Those that required no action at all and those that did require maintenance but were deferred until the end of the flying day. The first type, those that required no action, usually involved RPM or temperature variance. Typically, one of these parameters would exceed its limits for a short period of time and trigger a trim event. The duration was on the order of 10 or 15 seconds, then the problem would correct itself and the engine would operate normally for the remainder of the flight; however, since an event was recorded, the status panel indicated a no-go condition and the data clearly indicated that the event had occurred. It was also clear that the problem had corrected itself and the engine was in fact normal in all respects. These events stimulated considerable dialogue between ourselves, the aircrews and the contractors in trying to understand the cause. It was finally concluded that the events occurred during maneuvering flight and are inherent characteristics of the engine when operating under those conditions. The second category, deferred actions, were similar except that they were minor problems that amounted to fine tuning to correct a shift in control system rigging, or a marginal temperature control system. I should point out that in only one instance did the pilot also detect the problem. The point is, that early detection of these problems allowed corrective action to be taken before they degraded to the point that the pilot might have aborted and lost a sortie. It also allowed maintenance considerable flexibility in scheduling the repair action, which we think is a real benefit.

Regarding the three missed events. The first was a stall reported by the pilot. EHMS did not detect anything abnormal and we could not duplicate the problem on the ground. It is possible that the stall occurred during deceleration which the system is not programmed to detect; however, the pilot could not confirm that this was the case, so it was scored as a system miss. The second event was fluctuation of RPM, EGT, FF and nozzle, also reported by the pilot. In this instance, the pilot recorded six data samples during the event. However, none of these confirmed the problem. As a precaution, maintenance replaced the temperature amplifier and motor. The problem did not repeat so it was also scored as a miss. The final miss involved a low oil pressure problem reported by the pilot during a cross-country flight. When the aircraft returned, no data was available, apparently due to failure of battery powered memory.

In terms of the positive results, we are very pleased with the 92% event detection rate. Particularly, the significant increase in the percent detected by EHMS only (77% vs. 20%), as compared to the ATC evaluation. We attribute the difference to the more active mission which requires that the pilots attention be focused outside the cockpit much of the time. Manhour savings for trim was similar to ATC's experience, approximately three man-hours. This saving results from the difference in the time required to connect EHMS versus the standard trim test set with multiple connectors. The system aids the fault isolation process by providing accurate inflight data recorded at the time of the malfunction. The availability of this data has eliminated the need for ground run to fault isolate some problems. Also, some aborts were prevented because maintenance personnel were able to connect the DDU, analyze the problem and correct it in time for the aircrew to make their scheduled takeoff time. This is particularly important at Holloman because of the large number of aircraft using the single runway and range, windows for takeoff and range times must be met if the sortie is to be effective. We also saved sorties by turning some aircraft faster due to reduced fault isolation time. And as mentioned previously, early detection of minor problems allowed repair prior to their developing into major problems. Elimination of engine removal for test cell run is another significant factor. The capability to read engine performance in real time prevented a number of engine removals for functional check in the test cell. Most of these were associated with over "G" incidents which accounts for 16% of all unscheduled engine removals at Holloman. The last two items are somewhat intangible, but important nonetheless. Aircrews have commented that the modified aircraft seem to perform better and that they are more "comfortable" flying them.

Maintenance personnel like the system because they believe it helps them do their job better and faster. Although some commented that the system makes work because it detects things the pilot did not, obviously, that's a shortsighted viewpoint. We also learned a number of valuable lessons which we were able to apply to the A-10 evaluation at Myrtle Beach AFB.

These are some areas where improvement is needed if we are to realize the full capability of the system. Diagnostic capability was limited by the lack of a diagnostic handbook. Without such a handbook, diagnostic capability is limited to the individual's ability to analyze the data. Some individuals did extremely well, but others did poorly. This is being corrected in the A-10 program where we have a team of Air Force and contractor personnel working to develop a handbook. The LCF count was mechanized for the ATC mission where one hour of flight equals one LCF cycle. The one to one ratio does not apply to the Holloman environment. Analysis of mission profiles and hardware indicates that one hour of flight is equal to 2.2 LCF cycles. We are really interested in doing this job a little better because we are not very comfortable that mission profiles obtained by pilot interview are really representative. Data from mechanical counters on our F-5 aircraft suggest that may not even be close. This problem was also corrected on the A-10 aircraft. Trending is another area where we were unable to accomplish our objective. During the ATC evaluation, AFLC developed a computer trend program that appears to work, but our objective was to develop the capability to trend at base level where the information is needed. Our approach was to manually plot trend data automatically recorded during flight. In doing this, we experienced several problems. First, the J85 is a variable nozzle engine and data was recorded at mil power when the nozzle is controlled by the temperature limiting system, or at cruise power when the nozzle is controlled by throttle angle. Because of nozzle movement at mil power and insufficient stability criteria for sample recording we experienced a lot of data scatter. The cruise data was somewhat better but still affected by stability. The problem with cruise data is that flight to and from the work areas is in formation and unless the modified aircraft is flying lead, stability criteria for sample recording is not met. Increasing stability time compounds the problem. The second problem concerns defining what constitutes a significant trend. Even with the data scatter some small shifts were evident and by superimposing failures over the trend plots we concluded that some could have been predicted. However, when we tried to apply that experience to other engines exhibiting similar trends we did not find any evidence of failure nor did similar failures subsequently occur. Our conclusion is that before we can continue we must solve the stability problem. In the A-10 program, we have elected to have the aircrews fly for sixty seconds at stabilized power as a starting point to determine the stability time required for trending. We also need assistance from the technical community in defining what constitutes a significant shift and what the various combinations of parameter shifts represent for each model engine. Vibration also gave us some problems. First, the output was expressed in velocity rather than displacement as the T.O. limits are expressed. Consequently, while we could detect a shift from the baseline signature we could not determine when that shift was no longer acceptable in terms of exceeding established limits.

Additionally, we found engines having higher than normal baselines or that had shifted upward were normal when operated on the test cell. In the A-10 program the output is expressed in mils displacement which corrects that part of the problem, but there still appears to be some reliability problems to be solved. For example, fan vibration on one A-10 engine was recorded at 56 Mils for six minutes at idle power. Clearly, further work is needed in this area. "G" loading is another parameter that we believe is useful in a fighter aircraft system. If it had been available in the T-38 system, it would have aided our understanding of those no maintenance action events discussed earlier. It also would provide valuable data to substantiate our mission profiles. "G" loading has been incorporated into the A-10 system and is proving useful in understanding some of the TF-34 engine problems. As far as system reliability is concerned, the actual reliability won't be quantified until the data analysis is completed. However, we experienced failures of sensors and recorders at what appears to be a fairly high rate as compared to the earlier ATC evaluation. It is important to recognize that nothing was done in the way of refurbishing the equipment prior to our evaluation. A comparison of failure rates should provide some insight into the expected life of this equipment Since the equipment installed on the A-10s is either new or modified T-38 equipment that was refurbished, we expect the A-10 failure rate to be lower.

As I alluded to earlier, the data analysis is not complete. Our preliminary assessment is that the evaluation was successful in terms of identifying the positive and negatives of the system. If the improvements we talked about earlier are incorporated and proven, we would support incorporation of the system on TAC T-38 aircraft.

By way of future action on this program, we have to analyze the data and write the report. From this will come the decisions to continue or terminate. If the decision is continued, we must get the improvements incorporated, evaluated and analyzed and the results in time to meet a co-production decision date of December 1979.

BACKGROUND

- FOLLOW-UP TO ATC EVALUATION
  - 5 EHMS EQUIPPED AIRCRAFT
- 12 MONTH EVALUATION
  - HOLLOMAN AFB, NM
  - OCT 77 - SEP 78
- BLUE SUIT EVALUATION
  - PERIODIC CONTRACTOR VISITS

LG 1414

TAC EVALUATION

- 1963 ENGINE FLIGHT HOURS ACCRUED
  - AVERAGE 16.3 HOURS PER A/C PER MONTH
- 1160 SORTIES FLOWN
  - 917 GOOD FLIGHTS
  - 81 VALID HITS
  - 4 FALSE ALARMS
  - 15 OUT OF SCOPE
  - 140 NO MAINTENANCE ACTION
    - 82 DEFERRED MAINTENANCE ACTION
  - 3 MISS

LG 1415

TAC EVALUATION

- POSITIVE RESULTS
  - 92% EVENT DETECTION
    - 77% DETECTED BY EHMS ONLY
      - 20% DURING ATC EVALUATION
  - REDUCED MANHOURS FOR ENGINE TRIM
  - AIDS FAULT ISOLATION
  - REDUCED GROUND RUN
  - PREVENT ABORTS
  - ELIMINATED ENGINE REMOVAL FOR TEST CELL RUN
  - AIRCREW AND MAINTENANCE PERSONNEL SUPPORT
  - EXPERIENCE AIDED A-10 EVALUATION

LG 1417

TAC EVALUATION

- IMPROVEMENTS NEEDED
  - DIAGNOSTIC CAPABILITY NOT FULLY REALIZED
  - LOW CYCLE FATIGUE COUNT NOT REPRESENTATIVE
  - TRENDING NOT EFFECTIVE
  - VIBRATION DATA NOT RELIABLE
  - "G" LOAD DATA NEEDED
  - SYSTEM RELIABILITY APPEARS LESS THAN DURING ATC EVALUATION

LG 1418

PRELIMINARY ASSESSMENT

- SUCCESSFUL EVALUATION
- POTENTIAL FOR INCORPORATION IF IMPROVEMENTS ARE INCORPORATED AND PROVEN

LG 1419

FUTURE ACTION

- ANALYZE DATA AND REPORT
- DECISION TO CONTINUE/TERMINATE
- INCORPORATE AND TEST IMPROVEMENTS
- ANALYZE DATA AND FINAL REPORT
- A-10/T-38 CO-PRODUCTION DECISION, DECEMBER 1979

LG 1420

A-10 TEMS EVALUATION

BY

CAPT J. GISSENDANNER

SAALC/MMPRR

Kelly AFB Tx

AV 945-6001

HIGHLIGHTS

Flight evaluation began 1 Nov 78 for 12 months. They are currently preparing a sixth aircraft for a special investigative role. This plane will fly changes to the system before it is incorporated into the other aircraft. They are developing a diagnostic handbook, a master chip detector and parameter fluctuation monitoring.

PRIMARY TEST PURPOSE

DEFINE AND DEVELOP A PRODUCTION ENGINE DIAGNOSTIC SYSTEM FOR THE A-10/TF-34.

A-1C TEMS SERVICE EVALUATION

- 1 NOV 78 - 31 OCT 79
- FIVE TEMS-EQUIPPED ACFT (SIXTH IN SPECIAL INVESTIGATIVE ROLE)
- FIVE CONTROL GROUP ACFT
- ON-SITE TEST TEAM
- SERVICE EVALUATION PLAN
- DIAGNOSTIC HANDBOOK
- EXISTING AND SPECIAL DOCUMENTATION

A-10/TF34 TEMS - SPECIFIC OBJECTIVES

1. FAULT DETECTION/FAULT ISOLATION
2. TRENDING
3. TRIM BOX/VIBRATION ANALYZER
4. ETTR/LCF COUNTER
5. MANPOWER
6. AVAILABILITY
7. SUPPLY
8. OCM
9. RELIABILITY
10. MAINTAINABILITY
11. SUPPORT EQUIPMENT
12. FACILITIES
13. DEPLOYMENT
14. SOFTWARE
15. DIAGNOSTIC HANDBOOK
16. DATA SYSTEM INTERFACE
17. TRAINING
18. LIFE CYCLE COST

MEASURED DATA

PLA	N_G MECH
OAT	N_F MECH
T_{2c}	P_{OIL}
ITT	P_{FUEL}
$W_{F\ ACT}$	$N_{G\ CORR}$
P_{S3}	P_{AMB}
P_{T5}	W_F/P_{S3}

DIAGNOSTIC INDICATORS

400 CYCLE LOSS	(NOT DISPLAYED ON DDU)
W_F OVERRIDE	(AVAILABLE ON PRINTOUT)
BUILT IN TEST	
THRUST REDUCED	NA
SFC INCREASE	NA
COMPR/HP TURBINE	NA
FAN/LP TURBINE	NA
SLATS/HIGH AOA	NA
HIGH TEMP START	NA

COMPUTED EQUATIONS

N_G/N_F VS $EPR_{(CORE)}$	GROSS HEALTH
$N_{F\ CORR}$ VS $W_{F\ CORR}$	ENGINE EFFICIENCY INDEX (SFC)
$N_{F\ CORR}$ VS $T_{5\ CORR}$	FAN-SPEED RELATIONSHIP
$EPR_{(CORE)}$ VS $W_{F\ CORR}$	ENERGY CONVERSION INDEX
P_{T5} VS P_{s3}	CORE PRESSURE RELATIONSHIP
N_F VS OAT	FAN TRIM SPEED (DISPLAY, BUT NO PRINTOUT)
N_F VS T_{2c}	TRIM MARGIN
VG VS $N_{G\ CORR}$	VARIABLE GEOMETRY SCHEDULE

EVENTS

ITT OVERTEMP-LEVEL 1, 2		FUEL FILTER	ΔP
N_G/N_F OVERSPEED-LEVEL 1, 2		MASTER CHIP DETECTOR	
FLUCTUATIONS-LEVEL 1, 2		IDLE SPEED OUT	NA
(N_G, N_F, ITT, W_F, P_{S3})		ENGINE STALL	NA
OIL PRESSURE-LEVEL 1, 2		VG SCHEDULE OFF	
(LEVEL 1=HIGH/LOW, 2=FLUX)		VERTICAL ACCEL	NA
VIBRATION-LEVEL 1, 2		ETTR	NA
FUEL PUMP PRESSURE	NA		

INNOVATIONS/OPPORTUNITIES

- PARAMETER FLUCTUATION MONITORING
  (ITT, P_{S3}, RPM, W_f, P_{oil})
- MASTER CHIP DETECTOR
- ETTR REPLACEMENT
- COCKPIT DISPLAY
- AIRCRAFT VERTICAL ACCELEROMETER
- GUN FIRING
- GROUND STATION

EHMS HARDWARE

- AIRBORNE
  - SENSORS
  - ELECTRONIC PROCESSOR UNIT (EPU)
- GROUND
  - DIAGNOSTIC DISPLAY UNIT (DDU)
  - PERIPHERAL EQUIPMENT

LESSONS LEARNED

- ALLOW SUFFICIENT SHAKEDOWN PERIOD
- RETAIN KEY TEST PROGRAM PERSONNEL THROUGHOUT EVALUATION
- DETERMINE MOST SIGNIFICANT PARAMETERS / EQUATIONS FOR MONITORING AND TRENDING
- PROVISION FOR ADEQUATE SPARES SUPPORT
- PROVISION FOR ADEQUATE TECH DATA
- DESIGN AIRBORNE EQUIPMENT FOR ACCESSIBILITY
- INTEGRATE AIR CREWS INTO PROGRAM
- DETERMINE CONDITION OF ENGINES PRIOR TO START
- CONDUCT TEST AT OPERATIONAL SITE
- CONFIGURE ADEQUATE QUANTITY OF AIRCRAFT
- MONITOR CONTROL DATA

USAF TERMINOLOGY FOR SCORING ACCURACY AND EFFECTIVENESS OF TF34 AND F100 AUTOMATED DIAGNOSTIC SYSTEMS

BY

CAPT JOEL GISSENDANNER
SAN ANTONIO ALC/MMPRR
KELLY AFB TX 78241

AV 945-6001

HIGHLIGHTS

Automated Diagnostic system performance is categorized as good, hit, miss, false alarm, or out-of-scope. Methods are presented which allow comparison of performance between different applications.

ABSTRACT

USAF TERMINOLOGY FOR SCORING ACCURACY AND EFFECTIVENESS OF TF34 AND F100 AUTOMATED DIAGNOSTIC SYSTEMS

BY

CAPT JOEL GISSENDANNER
San Antonio ALC/MMPRR
Kelly AFB TX 78241

(512) 925-6001
AV 945-6001

AND

CAPT THOMAS A. KLIMAS
ASD/YZLD
Wright-Patterson AFB Oh 45433

(513) 255-6734
AV 785-6734

Since both the TF34 and F100 programs are similar in nature, standardization of certain terms is necessary. This is especially true in the area of scoring the accuracy and effectiveness of these diagnostic systems. The following terms and definitions were adopted for each. It is recognized that once the flight programs begin and data is gathered, minor changes may be necessary to cover all situations.

A-10/TF34 TEMS - F100 EDS Effectiveness Scoring Terminology

(Flight Categories)

1. *GOOD: TEMS/EDS indicates no discrepancy has occurred (TEMS status indicator - go) and the engines are indeed operational and capable of making a subsequent flight without maintenance.

a. Type One: The pilot and maintenance personnel along with TEMS/EDS did not note any discrepancies that would prohibit a subsequent flight. (TEMS status indicator - go).

b. Type Two: The pilot or maintenance personnel report a discrepancy for which TEMS/EDS is programmed to detect; however, TEMS/EDS indicates no problem. (TEMS status indicator - go). The reported discrepancy is found to be non-existent, non-engine related (cockpit instruments/indicators) or unconfirmed by subsequent troubleshooting.

2. *HIT: Flight in which an engine discrepancy has occurred and was correctly identified by TEMS/EDS. (All hit types carry equal weight).

a. Type One: TEMS/EDS alone correctly detects an engine discrepancy which requires corrective maintenance action. (TEMS/EDS status indicator no-go).

b. Type Two: TEMS/EDS along with the pilot and/or maintenance personnel detect an engine discrepancy which requires corrective maintenance action. (TEMS/EDS status indicator no-go).

c. Type Three: TEMS/EDS alone correctly identifies a discrepancy (usually a limit exceedance) but severity and duration of the problem does not warrant immediate maintenance action. (TEMS/EDS status indicator no-go).

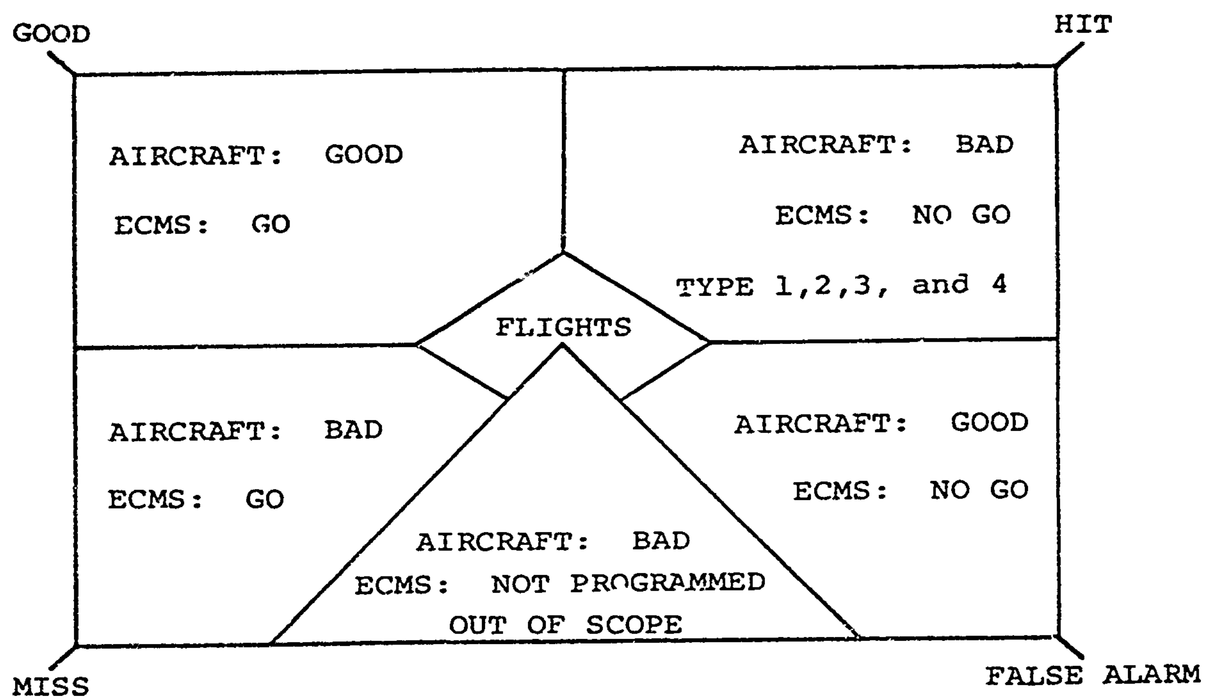
d. Type Four: An unusually high amount of peculiar data in the normal flight windows or from a pilot initiated data sample confirms an engine problem even though TEMS/EDS did not generate a malfunction record. The problem is identified by ground analysis of inflight TEMS/EDS data. The pilot or maintenance personnel may or may not have reported a discrepancy (TEMS status indicator - go).

*GOOD or HIT flights indicate correct assessment by TEMS/EDS.

3. MISS: TEMS/EDS recorded no discrepancy for which it was programmed despite the fact that such a discrepancy did occur. (TEMS status indicator - go). The discrepancy was reported by other detection means such as the pilot or maintenance personnel through inspection. Verification of the problem is a necessary prerequisite to confirm a "miss" and in some cases would require suspect component inspection/teardown.

4. OUT OF SCOPE: Flight in which an engine discrepancy has occurred but is not programmed to be detected by TEMS/EDS. (TEMS status indicator - go).

5. FALSE ALARM: Flight in which the TEMS/EDS incorrectly indicates an engine malfunction (TEMS/EDS status indicator no-go) when none has actually occurred. Verification of "no problem" would be made by maintenance personnel and in some cases would require suspect component inspection/teardown.



EFFECTIVENESS EVALUATION CATEGORIES

Success Ratios

The effectiveness of an EMS can be evaluated in terms of success ratios. Four terms may be defined for clarity:

1. GOOD - No problems and no EMS problem indications

2. MISS - Problem(s) exist with no EMS problem indication

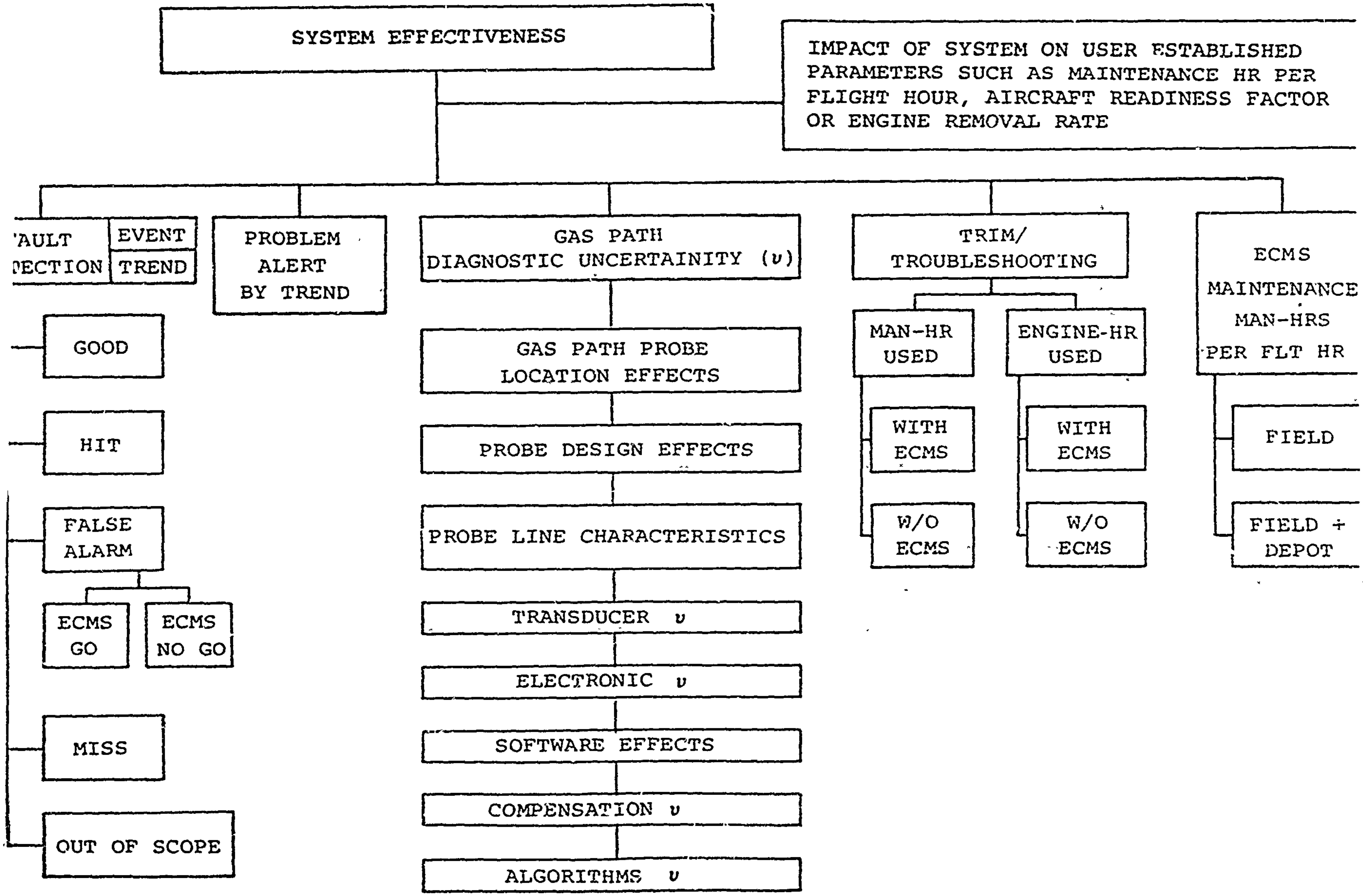
3. FALSE ALARM - No problem but EMS problem indication exists

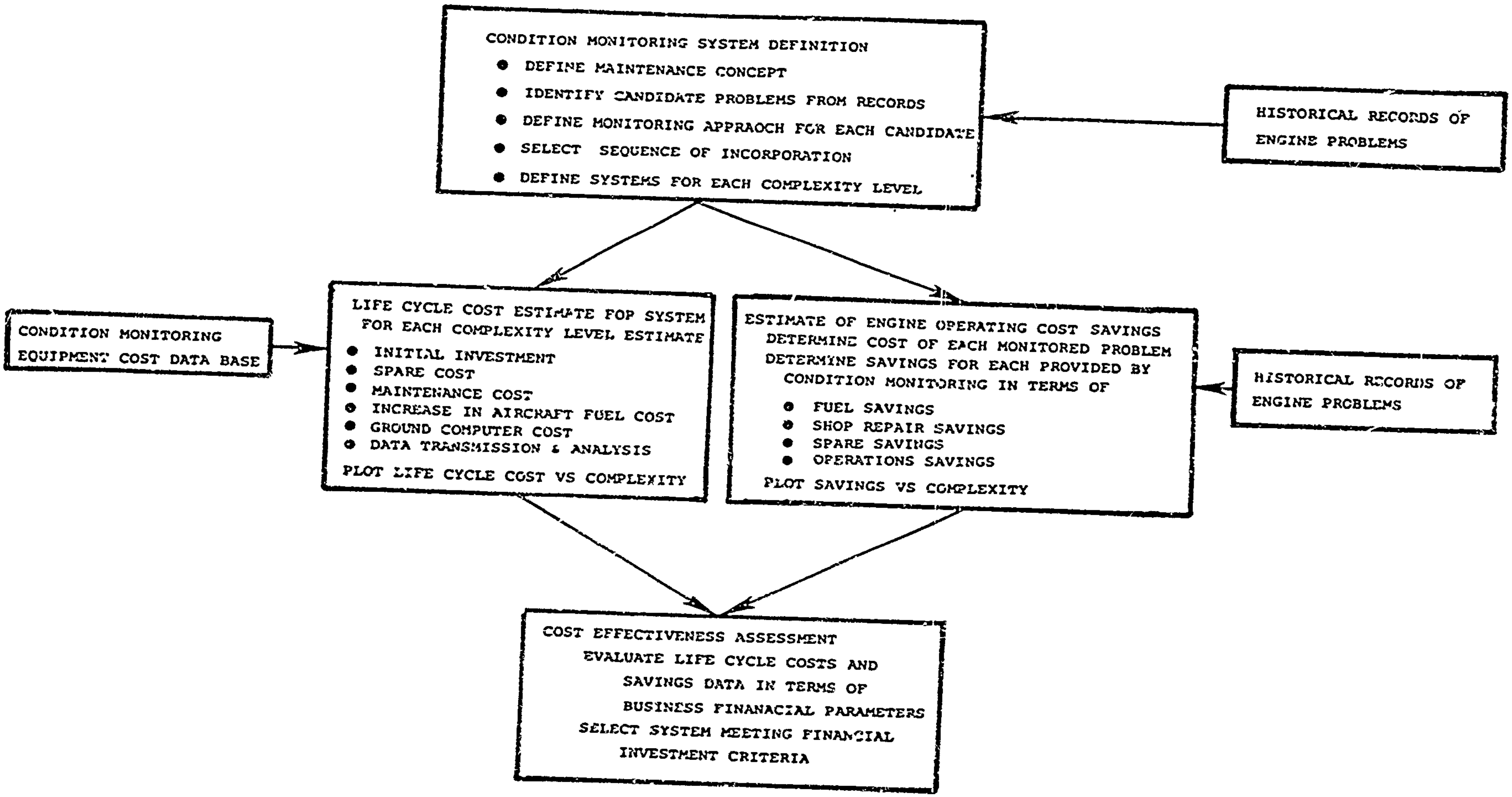
4. HIT - Problem(s) exist with EMS problem indication

All EMS situations fall into one of these categories.

Examples of success ratios are listed as follows:

RATIO	GOAL
GOOD	To approach 1.0 as engine matures
$\frac{\text{GOOD + HIT}}{\text{Total}}$	To approach 1.0 as EMS matures
$\frac{\text{1.0-FALSE ALARMS (EMS GO)}}{\text{Total}}$	To approach 1.0 as EMS matures
$\frac{\text{1.0-MISS (Programmed Events)}}{\text{Total}}$	To approach 1.0 as EMS matures for all possible events
$\frac{\text{1.0-MISS (Non-programmed Events)}}{\text{HIT}}$	To approach 1.0 as EMS and engine mature as system
$\frac{\text{HIT}}{\text{EMS problem Indications (FALSE ALARM + HIT)}}$	To approach 1.0 as EMS matures


SYSTEM EFFECTIVENESS
IMPACT OF SYSTEM ON USER ESTABLISHED PARAMETERS SUCH AS MAINTENANCE HR PER FLIGHT HOUR, AIRCRAFT READINESS FACTOR OR ENGINE REMOVAL RATE
'AULT TECTION
EVENT
TREND
GOOD
HIT
FALSE ALARM
ECMS GO
ECMS NO GO
MISS
OUT OF SCOPE
PROBLEM ALERT BY TREND
GAS PATH DIAGNOSTIC UNCERTAINITY (ν)
GAS PATH PROBE LOCATION EFFECTS
PROBE DESIGN EFFECTS
PROBE LINE CHARACTERISTICS
TRANSDUCER ν
ELECTRONIC ν
SOFTWARE EFFECTS
COMPENSATION ν
ALGORITHMS ν
TRIM/ TROUBLESHOOTING
MAN-HR USED
WITH ECMS
W/O ECMS
ENGINE-HR USED
WITH ECMS
W/O ECMS
ECMS MAINTENANCE MAN-HRS PER FLT HR
FIELD
FIELD + DEPOT



COST EFFECTIVENESS FLOW DIAGRAM

AEDC SUPPORT TO AIR FORCE

TURBINE ENGINE MONITORING SYSTEMS

(TEMS)

By

A. E. Burwell

AEDC /DOTA

AV 882-1520 X7791

HIGHLIGHTS

Regarding high accuracy pressure transducer test and development, Conrac West has not delivered units to AEDC. The non-delivery has delayed the F-100 program. AEDC is using available probes for a data base. Assessment of the F-100 thermal equilibrium revealed that anti-ice valve transients, climbs, and throttle jockeying require 30 to 65 seconds to stabilize. The 1979 program includes F-15 and F-16 EDS (ASD/YZ100 and AFLC/LOP), the A-10/TF-34 EHMS handbook development, and EDS probes for PT2.5C, T.2.5C, T3S.

1. AEDC became involved in TEMS in FY77 with the development of the F100 engine diagnostic system (EDS). The program management can be seen in Figure 1. The development areas to be supported were system design evaluating, diagnostic system/engine hardware evaluation, and flight test data correlation. Thus far, the AEDC support has been directed toward system design evaluation. In FY78 support was provided in the areas shown in Figure 2.

2. An engine test was conducted in the Engine Test Facility at AEDC to assess the thermal response characteristics of the F100 engine when subjected to the disturbances shown in Figure 3. The conditions tested and the corresponding results can be seen in Figures 4-9.

3. Perhaps the single largest contribution made by AEDC was the evaluation of EDS software logic. The software logic was programmed on a general purpose computor at AEDC and evaluated using existing F100 engine data from previous tests conducted at AEDC. The "fresh look" approach taken during the evaluation identified potential problem areas which were restructured prior to hardware incorporation. The effort reduced programming costs and time requirements.

4. AEDC has been authorized to contract the Conrac Corporation to develop high temperature/high accuracy/pressure transducers. While the development has required a substantial amount of time, the resultant product should provide in-flight data that is highly accurate. The requirement lies in the need to fault isolate engine deterioration to a modular level. Once the transducers are received, they will be tested in a laboratory and in the AEDC engine test cell.

5. AEDC had initially planned to evaluate some of the engine pressure and temperature probes that were being developed for the EDS; however,

the availability of hardware has been such that a complete evaluation could not be conducted. Analysis was conducted on the production fan discharge pressure probe to allow a correlation to be made between it and the redesigned EDS probe. The correlation will be completed after testing the redesigned probe.

6. AEDC is to be involved in an evaluation of the hardware/software assembly at P&WA. The task could not be conducted in FY78 and is now scheduled for FY79. The AEDC involvement will allow an independent assessment to be made of the design configuration and will provide the Air Force with a working knowledge of the system capabilities.

7. The AEDC philosophy has always been to test prior to flight. AEDC has recommended that a "full up" system be tested at AEDC prior to flight test to demonstrate the system design requirements and the system/engine compatibility under tightly controlled conditions. The testing need has been recognized; however, it has not been specifically identified in the schedule of events. If the testing occurs it will be during late FY79.

8. The FY79 TEMS project will require continued support in the areas previously mentioned and support to A-10/TF34 TEMS. The organizational support for the effort is shown in Figure 10. AEDC is tasked with providing an independent evaluation of the software logic similar to the EDS activity and with supporting the development of the diagnostic handbook for the system. The schedule of support is undefined at this time.

9. AEDC has become closely involved with the development of the TEMS within the Air Force. AEDC views the involvement as an opportunity

and a challenge. It is an opportunity to assist in the development of a greatly needed tool. It is a challenge to make a good tool better.

and a challenge. It is an opportunity to assist in the development of a greatly needed tool. It is a challenge to make a good tool better.

FY78 AEDC SUPPORT TO THE EDS

- ENGINE THERMAL EQUILIBRIUM TEST ANALYSIS
- LOGIC DIAGRAM EVALUATION
- HIGH TEMPERATURE/HIGH ACCURACY PRESSURE TRANSDUCER TEST AND EVALUATION
- PROBE EVALUATION
- HARDWARE/SOFTWARE ASSEMBLY EVALUATION AT P&WA
- ALTITUDE CALIBRATION
- CONSULTING

F-100 ENGINE THERMAL EQUILIBRIUM ASSESSMENT

OBJECTIVE: TO ASSESS ENGINE THERMAL EQUILIBRIUM AND STABILIZATION TIME FOR:

- ANTI-ICE VALVE TRANSIENTS
- SMALL THROTTLE SNAPS
- NEAR CONSTANT AIRSPEED CLIMB

F-100 ENGINE THERMAL EQUILIBRIUM ASSESSMENT

ANTI-ICE VALVE TRANSIENTS

ALT/KCAS	POWER LEVER ANGLE, DEG	VALVE TRANSIENT
8K/375 (COLD DAY)	40	OPEN
8K/375 (COLD DAY)	40	CLOSED
8K/375 (COLD DAY)	86	OPEN
8K/375 (COLD DAY)	86	CLOSED
25K/325 (COLD DAY)	86	OPEN
25K/325 (COLD DAY)	86	CLOSED

ENGINE SETTLING TIMES FOLLOWING OPERATION OF THE ANTI-ICE VALVE

ALTITUDE/KCAS POWER LEVER ANGLE	8,000/375 40^{o}	8,000/375 86^{o}	25,000/325 86^{o}
PARAMETER CATEGORY	MAXIMUM SETTLING TIME, SEC		
A. CIVV, RCVV, AJ, GAS PATH PRESSURE AND TEMPERATURE	30	55	60
B. OIL SYSTEM	>>>65	>>>65	>>>65

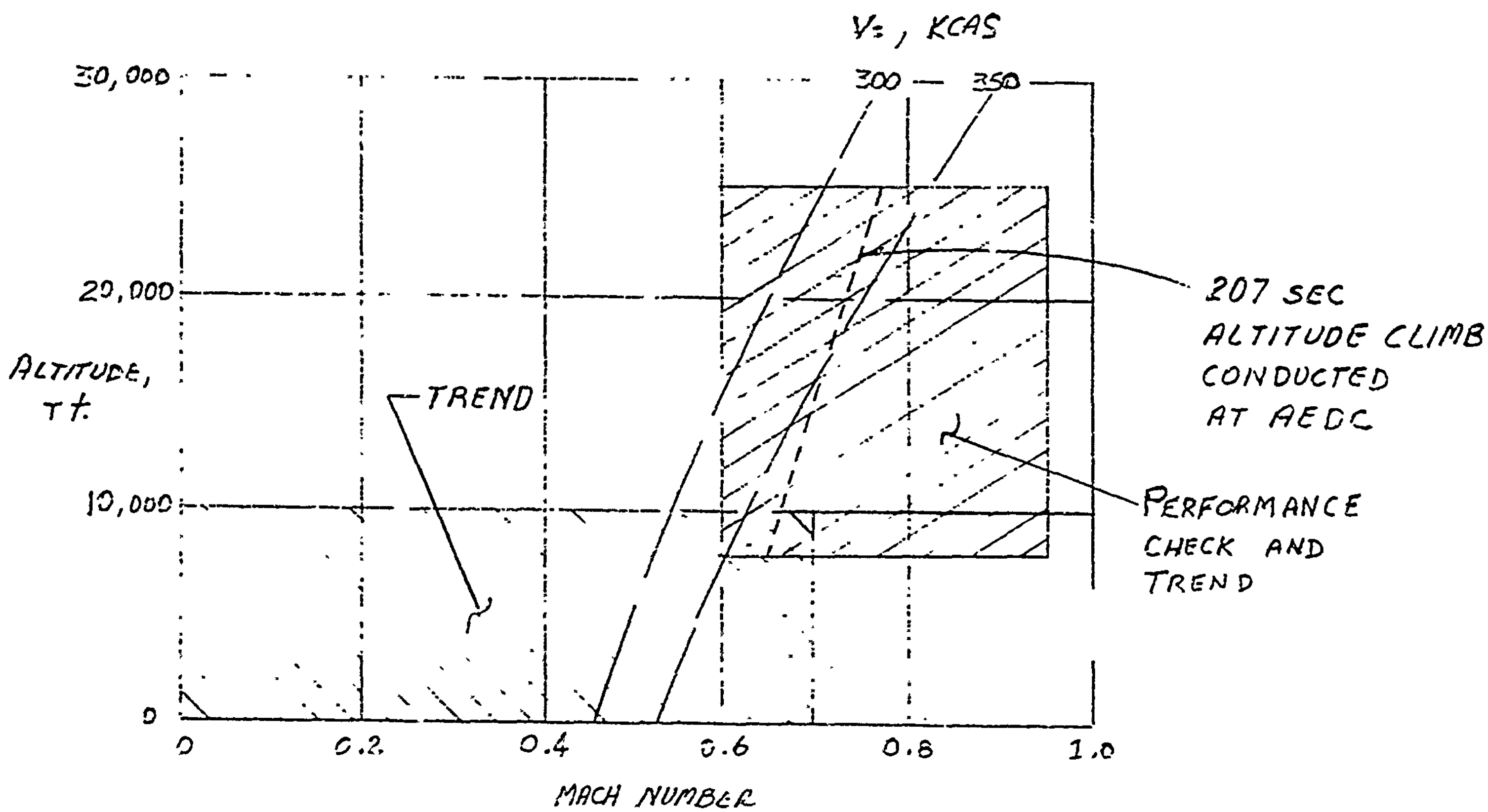
F-100 ENGINE THERMAL EQUILIBRIUM ASSESSMENT

SMALL THROTTLE SNAPS

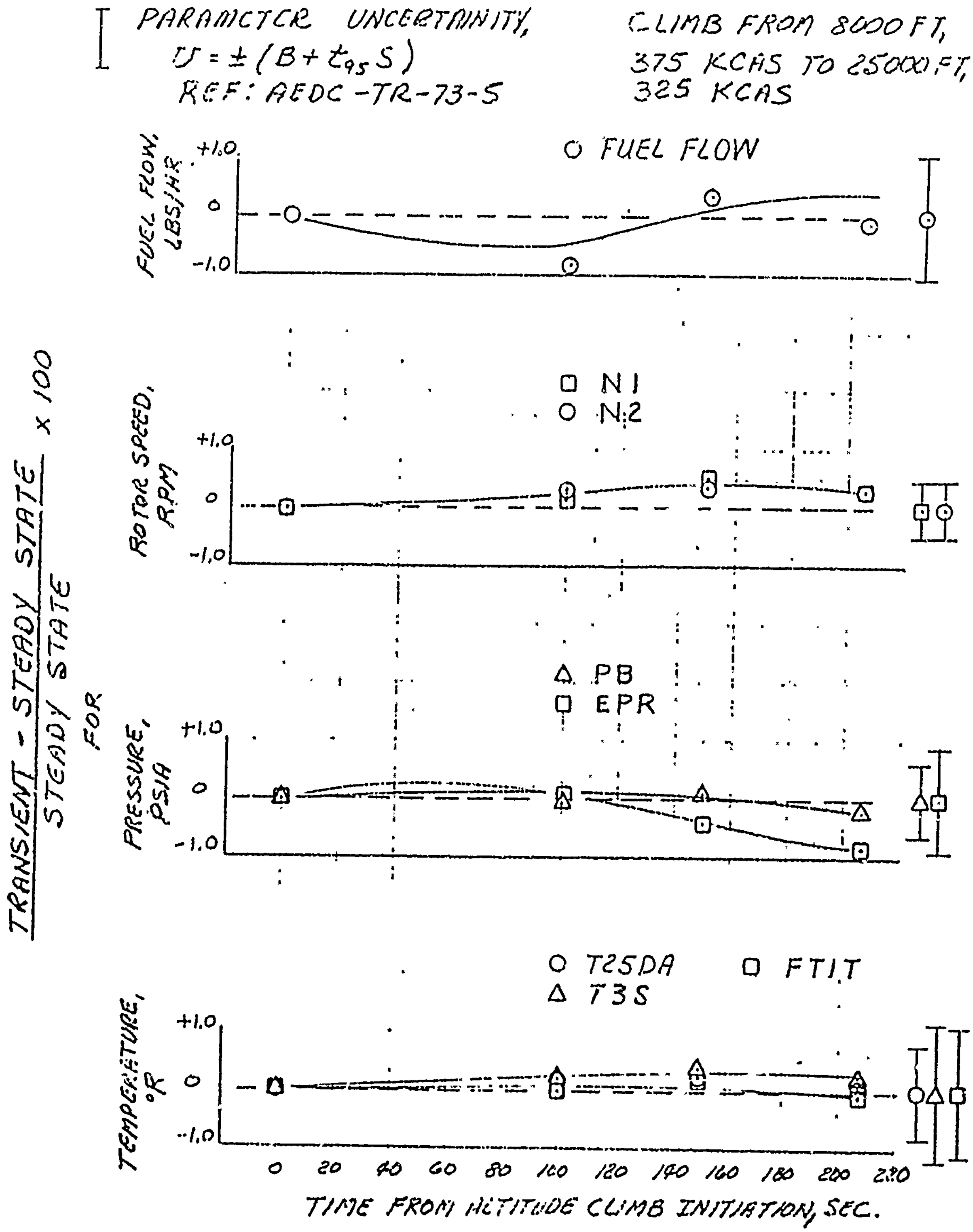
ALT/MO	POWER LEVER TRANSIENT
13K/0.4 (STANDARD DAY)	SNAP FROM N2 = 9,380 RPM TO N2 = 10,080 RPM
13K/0.4 (STANDARD DAY)	SNAP FROM N2 = 10,080 RPM TO N2 = 10,780 RPM
13K/0.4 (STANDARD DAY)	SNAP FROM N2 = 10,780 RPM TO N2 = 10,080 RPM
13K/0.4 (STANDARD DAY)	SNAP FROM N2 = 10,080 RPM TO N2 = 9,380 RPM

ENGINE SETTLING TIME FOLLOWING HIGH PRESSURE ROTOR SPEED SNAPS AT 13,000 FT ALTITUDE, MACH NO. 0.4

HIGH PRESSURE ROTOR SPEED, N2, TRANSIENT	10,080 ↑ 9,380	10,780 ↑ 10,080	10,780 ↓ 10,080	10,080 ↓ 9,380
PARAMETER CATEGORY	MAXIMUM SETTLING TIME, SEC			
A. CIVV, RCVV, AJ, GAS PATH PRESSURE AND TEMPERATURE	60	83	77	70
B. OIL SYSTEM	>>>60	>>>60	>>>60	>>>60



PROPOSED TREND/ PERFORMANCE CHECK WINDOWS



DIFFERENCES BETWEEN TRANSIENT AND STEADY STATE MEASUREMENT OF EDS PARAMETERS DURING AN ALTITUDE CLIMB AT NEAR CONSTANT CALIBRATED AIRSPEED AND INTERMEDIATE POWER

Fig 9

CWC
4/19/78

TEMS TEST MANAGEMENT

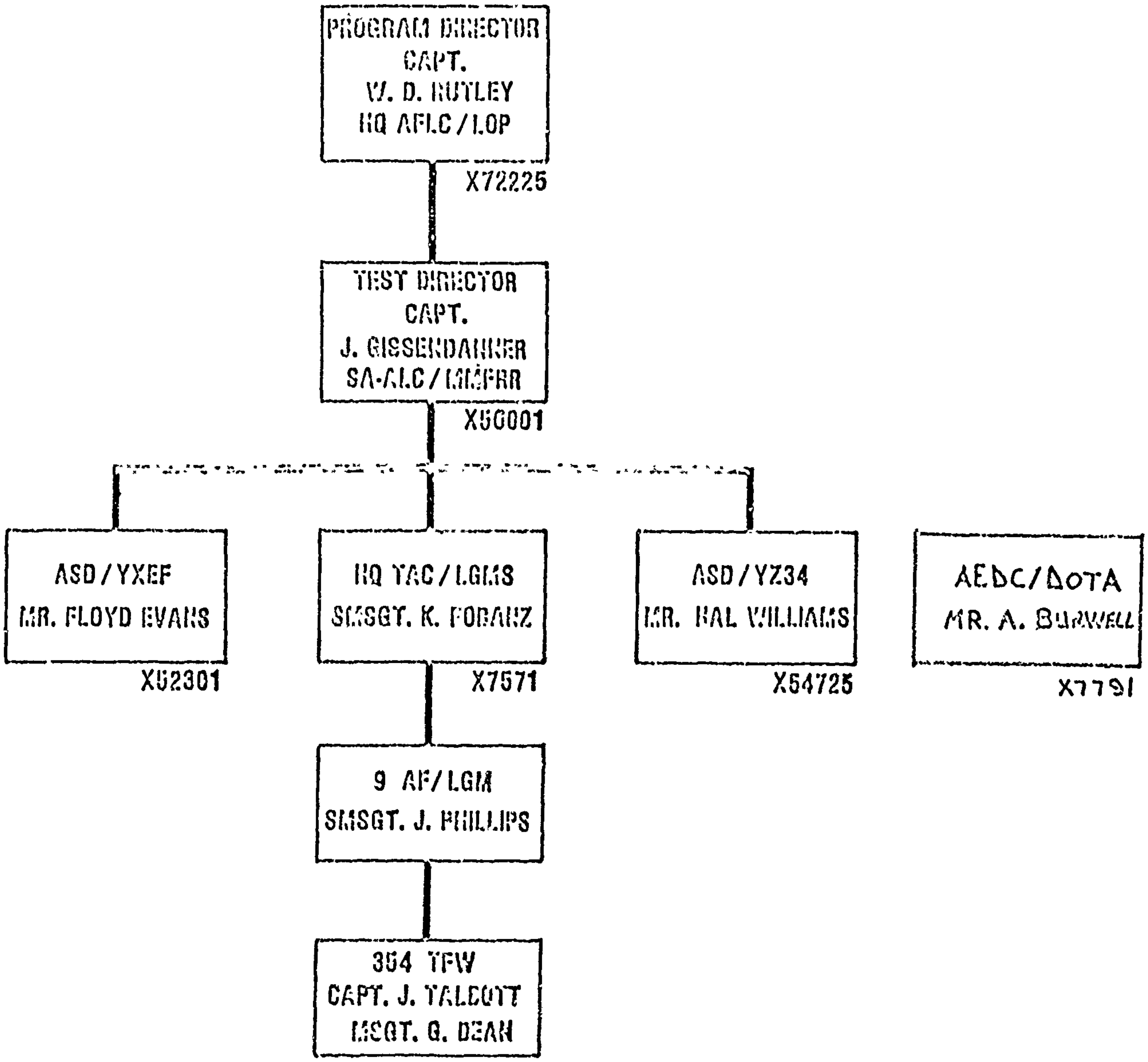


FIGURE 10

B-1 CITS FLIGHT TEST RESULTS

BY

MR. DON PIERATT

ASD/ENEG/ WPAFB OH 45433

AV 785-3552

HIGHLIGHTS

The system provides in-flight fault detection and isolation. A fault is mission power loss. CITS detects incipient failures and has detected 95% of, and isolated 75% of, line replaceable units (LRU).

The system covers 1800 LRU's with 5250 tests every 30 seconds on 27 non-avionics units (2584 parameters) and 13 avionics units (1200 parameters) with a 55 lb. 1 cu. ft. box. The sensors are in a good environment inside the fuel-cooled processor box. Data is recorded at 5 second intervals. The parameters include turbine blade temperature.

Conclusions: use a minimum number of judiciously selected parameters; continuous recording is not required.

NOTE: This presentation was prepared by Mr. Don Pieratt, ASD/ENEGM/53552. Mr Pieratt was unable to attend the Tri-Service Meeting. L/C Pettigrew presented Mr. Pieratt's briefing in his absence.

The Central Integrated Test Subsystem

An on-board test system was developed for the B-1 aircraft to allow the B-1 to meet self sufficiency requirements and to reduce the maintenance manhours per flight hour. The on-board test subsystem, called the Central Integrated Test Subsystem (CITS), continuously monitors all subsystems, of which there are twenty seven, both in-flight and on the ground and displays/records failed modes of operation and fault isolates to the Line Replaceable Unit (LRU) level.

The basic CITS is a digital computer controlled test system using a stored real-time software program to control data acquisition, data processing and data dissemination. A Manchester coded serial digital data buss communicates between the CITS digital computer and the CITS Data Acquisition Units, the Control Display, the Airborne Printer and the Magnetic Tape Maintenance Recorder.

One of the aircraft systems monitored and tested by the CITS is the F101 engine developed by General Electric. The CITS parameters and the test techniques were jointly developed by General Electric and Rockwell International in parallel with development and test of the F101 engine.

There are twenty seven engine parameters plus five airframe/aero parameters which are monitored and processed by the CITS. These parameters, are used for fault detection, fault isolation, trending and low cycle fatique counting. Thirteen of the engine analog parameters are input to the CITS processor where they are converted to a digital data system before sending them to the central CITS computer. The remainder of the parameters are furnished direct to the CITS.

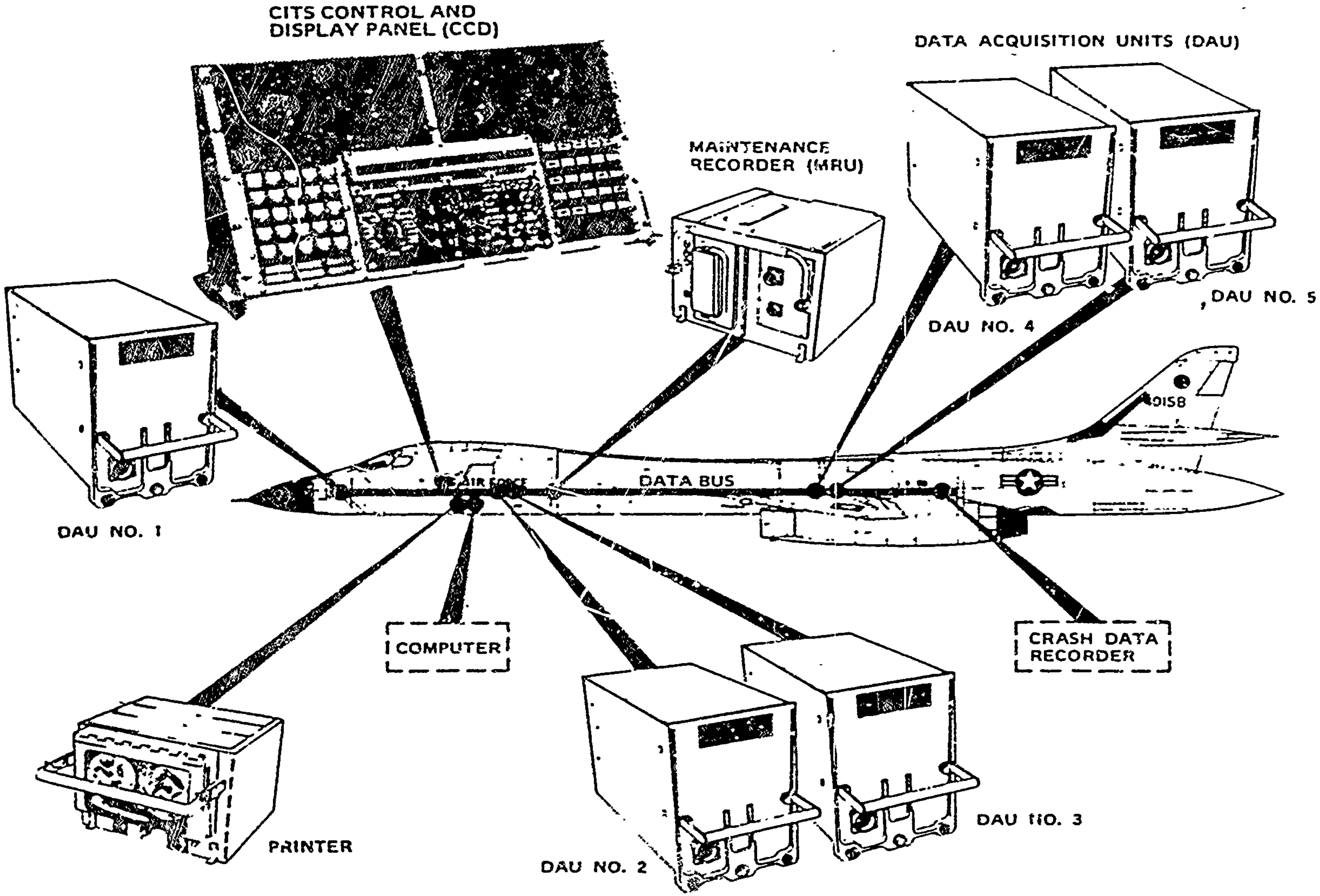
The CITS was operational on the first flight of the first B-1 Flight Test aircraft. It has been operational on the two following aircraft and will be on the fourth flight test B-1. Although in a flight test status itself and functioning with an operational computer program, the CITS also furnishes fifty two engine parameters direct to the flight test recorders through a program which interleaves that data with the normal program.

Because of the fact that the CITS is a moderately complex system and was itself to be in a flight test status, problems were anticipated and plans were made to prior to the first flight correct any deficiencies found during flight testing. Problems were anticipated particularly with the computer logic and software programs. These problems did occur as expected, manifesting themselves primarily as false failures being reported. Although extensive laboratory simulation was conducted, and some problems were corrected, only the true flight regime disclosed all the errors. Overall, the CITS functioned better than expected and has proven to be a benefit to the aircrew and the maintenance personnel. Currently, on the third aircraft, only approximately four false failures out of more than five thousand tests are being experienced on each flight.

CITS OBJECTIVES

- IN-FLIGHT FAULT DETECTION/ISOLATION
  - FAULT DEFINED AS "MISSION POWER LOSS"
  - DETECT 95% OF FAULTS
  - ISOLATE TO CORRECT LRU 75% OF TIME
- DETECT INCIPIENT FAILURES
- ACQUIRE TREND DATA
- SUPPORT "ON CONDITION MAINTENANCE" CONCEPT

CITS SYSTEM



CITS CONTROL AND DISPLAY PANEL (CCD)
DATA ACQUISITION UNITS (DAU)
MAINTENANCE RECORDER (MRU)
DAU NO. 4
DAU NO. 5
DAU NO. 1
DATA BUS
COMPUTER
CRASH DATA RECORDER
PRINTER
DAU NO. 2
DAU NO. 3

CITS SYSTEM BLOCK DIAGRAM

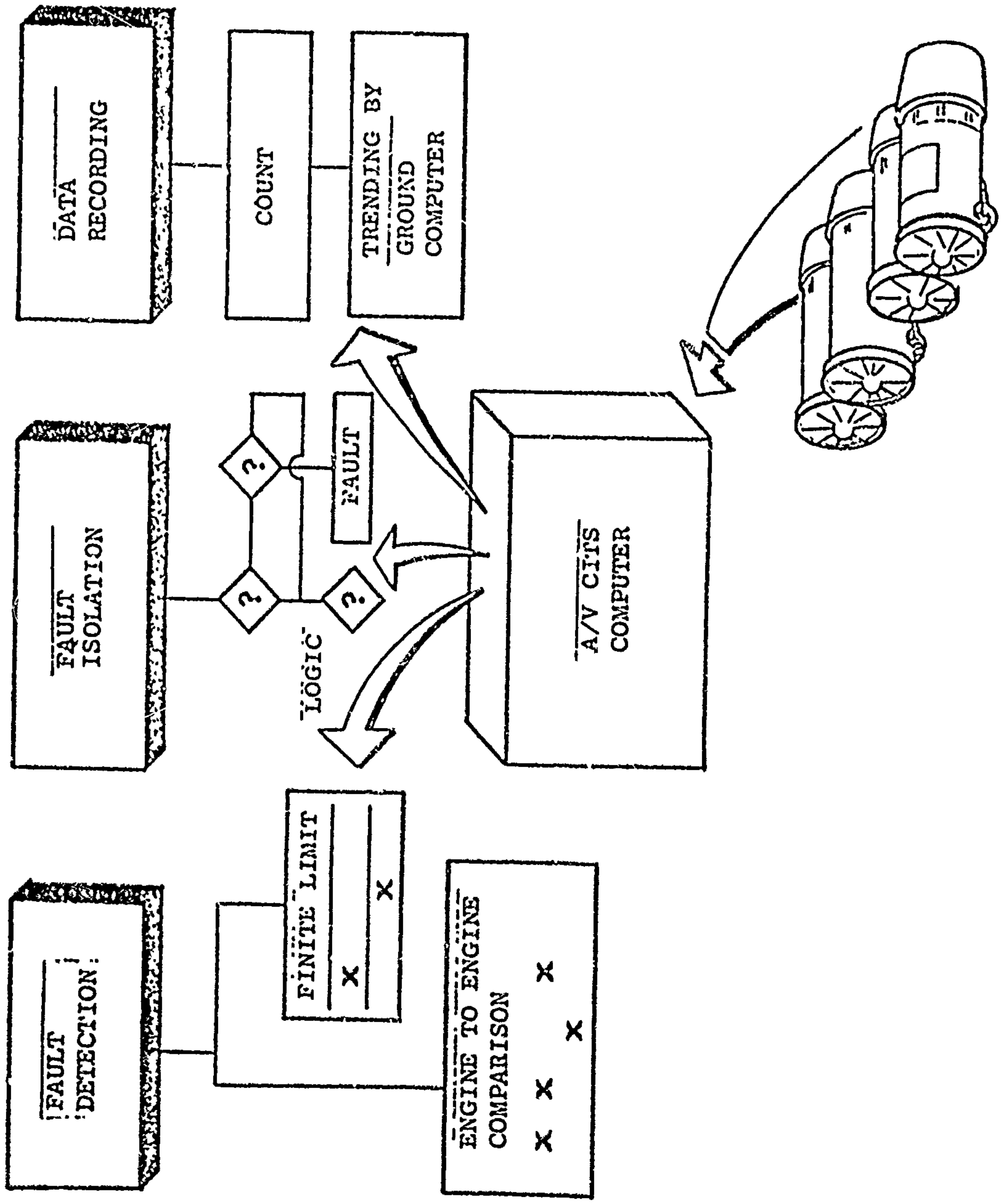
- CITS IS A COMMAND RESPONSE TYPE DATA BUS SYSTEM CONTROLLED BY CITS COMPUTER. IT IS A FORERUNNER OF THE MIL–STD–1553A BUS, AND PROVES THE DATA BUS CONCEPT OF MANY MODULES SHARING A COMMON DATA BUS.
- CITS CONTAINS 5 DATA ACQUISITION UNITS (DAU)
  - THE DAU'S INTERFACE THE EXTERNAL SENSORS, CONDITION THE DATA AND TRANSMIT IT VIA THE DATA BUS, TO THE CENTRAL COMPUTER.
- THE AIRBORNE PRINTER PROVIDES THE CREW WITH HARD COPY OUTPUT FROM CITS.
  - THE PRINTER RECEIVES DATA VIA THE DATA BUS FROM THE COMPUTER, IT CONVERTS THE DATA AND PRINTS IT ON PAPER TAPE.
- THE CREW CONTROL AND DISPLAY PANEL PROVIDES THE CREW WITH A PANEL DISPLAY OF THE SYSTEM/EQUIPMENT STATUS AND PROVIDES FOR MANUAL INPUTS.
- THE MAINTENANCE RECORDER IS A MAGNETIC TAPE MASS DATA STORAGE DEVICE.
  - THE CITS SYSTEM RECORDS ALL FAILURES WHEN THEY OCCUR AND PROVIDE PERIODIC RECORDINGS OF ALL SYSTEM PARAMETERS, INCLUDING THINGS LIKE ENGINE TREND DATA.
  - THE DATA IS INTERPRETED LATER BY GROUND DATA REDUCTION EQUIPMENT.

B1 CITS SYSTEM

- TEST AIRCRAFT SUBSYSTEMS
  - SUBSYSTEM INSTALLATION CHECK OUT
  - PRE–FLIGHT CHECKOUT
  - IN–FLIGHT PERFORMANCE MONITORING AND RECORDING
  - POST–FLIGHT CHECKOUT
- PROVIDE AIRCREW WITH OPERATIONAL READINESS DISPLAY
  - DISPLAY OPERATIONAL STATUS OF SUBSYSTEMS
  - IDENTIFY FAILED MODES OF SUBSYSTEMS
- IDENTIFY FAILED LRU
  - ON BOARD FAULT ISOLATION
- PROVIDE TEST DATA AND MAINTENANCE RECORDS FOR GROUND CREW
  - ASSIST IN PREVENTIVE MAINTENANCE BY IDENTIFYING OUT OF TOLERANCE EQUIPMENT
  - MINIMIZE THE NEED FOR GROUND EQUIPMENT (AGE)

B1 CITS SYSTEM (CONT.)

- CITS INTERFACES WITH 29 AIRCRAFT SUBSYSTEMS, MONITORING APPROXIMATELY 3000 ANALOG, DIGITAL AND DISCRETE PARAMETERS VIA 5 STRATEGICALLY PLACED DATA ACQUISITION UNITS (DAU)
- TYPICAL AIRCRAFT SUBSYSTEMS MONITORED:
  - ENGINES
  - HYDRAULICS
  - ELECTRICAL DISTRIBUTION
  - NAVIGATION
  - COMMUNICATION
  - FUEL MANAGEMENT
  - FLIGHT MANAGEMENT
  - FLIGHT CONTROL
  - ENVIRONMENTAL
  - STRUCTURAL
  - FIRE PROTECTION
  - OFFENSIVE AND DEFENSIVE ECM SYSTEMS
  - WEAPONS SYSTEMS



FAULT DETECTION
FINITE LIMIT
ENGINE TO ENGINE COMPARISON
FAULT ISOLATION
LOGIC
FAULT
A/V CITS COMPUTER
DATA RECORDING
COUNT
TRENDING BY GROUND COMPUTER

F101/B1 AVAILABLE PARAMETERS AND USE

ENGINE CITS PARAMETERS	FAULT DETECTION	FAULT ISOLATION	TRENDING	CYCLES
VIBRATIONS 1, 2 & 3	X	X	X	
LUBE PRESSURE	X	X	X	
LUBE QUANTITY	X	X	X	
LUBE TEMPERATURE	X	X	X	
ANTI-ICING		X	X	
TURBINE BLADE TEMPERATURE	X	X	X	X
FAN SPEED	X	X	X	X
CORE SPEED	X	X	X	X
FAN INLET VANE ANGLE	X	X	X	
EXHAUST NOZZLE AREA	X	X	X	
FAN DUCT MACH NUMBER	X	X	X	
AUGMENTOR CONTROL VALVE	X	X		
FAN DISCHARGE PRESSURE	X	X	X	
POWER LEVER ANGLE	X	X	X	
FAN INLET TEMPERATURE	X	X	X	
COMPRESSOR DISCHARGE PRESS.	X	X	X	X
4 TORQUE MOTOR CUR.		X		
AUGMENTOR PERMISSION SIG	X	X		
AUGMENTOR FUEL PRESSURE	X	X		
FLAME DETECTOR SIGNAL	X	X		X

BENEFITS OF CITS

- CITS DATA INVALUABLE IN TROUBLESHOOTING
  - FLT. 3-8, CITS DETECTED "IGV's OFF SCHEDULE"
    - DATA CONFIRMED FAULT
    - REPLACED AFT CONTROL
    - FOUND BAD IGV MODULE IN AFT CONTROL
  - FLT. 3-30 & 31, CITS DETECTED "IGV's OFF SCHEDULE"
    - DATA CONFIRMED IGV's INTERMITTENTLY OFF SCHEDULE
    - REPLACED AFT CONTROL
    - FOUND BAD IGV MODULE IN AFT CONTROL
  - FLT. 3-43, CITS DETECTED "LOW LUBE LEVEL"
    - POST FLIGHT INSPECTION REVEALED LOOSE FITTING AND WETTED FAN DUCT
    - GROUND RUN INDICATED PROBLEM STILL EXISTED
    - REMOVED ENGINE - FOUND CRACKED FRAME STRUT
  - A/C 2 GROUND RUN, CITS DETECTED "IGV's OFF SCHEDULE" AND ISOLATED TO "IGV ACTUATOR"
    - GROUND CREW IGNORED CITS MESSAGE AND REPLACED AFT CONTROL AND CABLES, ONE AT A TIME, WITHOUT FINDING PROBLEM
    - REPLACED IGV ACTUATOR - CORRECTED PROBLEM

BENEFITS OF CITS (CONT'D)

- A/C 1 GROUND RUN, FIRST TWO PV ENGINES OPERATING LINES ADJUSTED
  - ADJUSTMENT BASED ON CITS DATA
  - WITHOUT DATA WOULD HAVE REQUIRED TEST CELL RUN
- ALL A/C, ENGINE PERFORMANCE TRENDING
  - BASED ON POST FLIGHT RUN-UPS
  - DATA USED TO MAKE ENGINE CHANGE JUDGEMENTS
  - ENGINES RANKED BY TC LEVEL

BENEFITS OF CITS (CONT'D)

- USEAGE TRACKING FROM CITS TAPES
  - FLIGHT PROFILES PLOTTED
  - TIME @ TEMPERATURE DATA CAPTURED
  - PLA CYCLES COUNTED
  - PROFILE DATA USED IN DESIGN OF ACCELERATED MISSION TESTS
  - CITS DATA PROFILES BEING USED IN HIGH THRU FLOW TURBINE PROGRAM
    - COMPARE SEVERITY BETWEEN STICK MISSION AND ACTUAL ENGINE USAGE
    - DETERMINE SEVERITY RANGES OF ACTUAL USAGE
    - DETERMINE MOST INFLUENTIAL MISSION LEGS

B-I CENTRAL INTEGRATED TEST - F101 ENGINE

- CONCLUSIONS

  - THE B-I CITS HAS DEMONSTRATED THAT ON-BOARD PROCESSING WITH RECORDING OF SELECTED DATA IS THE CORRECT APPROACH
  - CONTINUOUS RECORDING IS NOT REQUIRED
  - A MINIMUM NUMBER OF PARAMETERS SHOULD BE CHOSEN CAREFULLY AND JUDICIOUSLY
  - A GROUND DATA PROCESSING SYSTEM IS REQUIRED TO PROCESS COLLECTED IN-FLIGHT DATA
  - IMMEDIATE PROCESSING OF COLLECTED IN-FLIGHT RAW OR PARTIALLY PROCESSED ENGINE DATA IS RECOMMENDED

ADEMS II FLIGHT TEST UPDATE

BY

1ST LT J. EDENS

ASD/YZEA WPAFB OH

AV 785-2892

HIGHLIGHTS

The flight evaluation runs from 1 Nov 77 to 30 Apr 79. The monitored parameters include:

11 from aircraft instruments - 2 temperatures
2 RPM, 2 pressures, 3 on-off signals
1 flow, 1 position

7 from MADAR - 3 pressures, 1 position,
3 temperatures

23 from ADEMS sensors - 4 temperatures,
5 pressures, 3 oil contaminations,
7 accelerations, 3 flow, 1 position

The hot section uses the CITS optical pyrometer to measure the first stage turbine blade temperatures. Bearing and gear vibration is sensed by externally located accelerometers. Dynamic wear is determined from a vortex lubricant sensor for wear particle accumulation. Magnetic chip detectors are also used.

The system features airborne limit exceedance, trend data, pre/post flight failure data, hrs/takeoffs until T54 margin, data scanning to alert the crew to FOD/DOD, T54 overtemp and low lubrication pressure.

ADEMS II

ADVANCED DIAGNOSTIC ENGINE MONITORING SYSTEM

ADEMS II

- JOINT PROJECT WITH THREE MAJOR COMMANDS (MAC-AFLC-AFSC)
- GE AWARDED CONTRACT - FEB 76
- ADEMS II IS INSTALLED ON 1 ENGINE OF 1 C-5A AIRCRAFT (TF39-GE-1A)
- NON-INTERFERENCE WITH THE NORMAL OPERATION AND MISSION OF THE AIRCRAFT
- GROUND PROCESSING - DONE AT WPAFB, OHIO, AND SENT TO GE, EVENDALE, OHIO, FOR EVALUATION AND TREND ANALYSIS

ADEMS II

The objectives of this program are to design, develop, and flight test an integrated system of advanced state-of-the-art computative and sensing techniques that collectively form an Advanced Diagnostic Engine Monitoring Systems (ADEMS II) and to evaluate the effectiveness of this system in enhancing the operation and maintenance scheduling of an in-service aircraft engine. ADEMS II will be installed in an Air Force-selected operational' C-5A aircraft for the flight evaluation of its capabilities in monitoring one of the TF39-GE-1A engines and will not interfere with scheduled aircraft/engine maintenance and operation.

This program will: (1) provide valuable information on the operation effectiveness of advanced diagnostic engine monitoring techniques; (2) determine the usefulness when incorporated into a diagnostic system for reducing field maintenance work throught improved fault isolation; and (3) establish engineering guidelines for diagnostic engine monitoring system application in future military aircraft.

This program will be conducted as a six (6) phase, 42 month effort to design, fabricate, system test, and flight test an Advanced Diagnostic Engine monitoring System (ADEMS II). Following an initial checkout period, the system will be operated and evaluated on a non-interference basis for a period of 18 months. The data collected and analyzed during this period of the total program will provide valuable information on the operational effectiveness of the individual ADEMS II subsystems and the effectiveness of the ground processing software. This experience will enable guidelines to be established for the application of Condition Monitoring systems to future military aircraft.

The ADEMS II flight evaluation program will apply, primarily, existing demonstrated condition monitoring technology in a system engineered concept, with a high probability of success. However, in some cases, the ADEMS II program will provide the first extensive flight test operation of such concepts and equipment as the internally mounted, externally removable bearing accelerometer, and the fiber light pipe coupled turbine blade pyrometer. The potential problem areas of the ADEMS II program are associated with their on-board performance in the airborne environment and the system interaction with the operational aircraft mission profiles.

ADEMS II will employ state-of-the-art hardware possessing the capability to withstand the environment and having the capability of high scan rates to minimize engine variation effects on data point parametric correlation and to enhance the validity of data taken at takeoff. The airborne system will incorporate: (1) Airborne Fault Detection, (2) Pre- and Post-Failure Event Recording; (3) Airborne Limit Exceedance Display; and will (4) record data for ground processing for the development and definition or realistic and practical techniques for predicting maintenance requirements via trending analysis.

The overall system capability, as defined hereafter, will incorporate those monitoring techniques considered to have a high probability of providing meaningful data to the flight crew, the ground maintenance activity, and for logistics support management.

ADEMS II will provide air crew alert of the following:

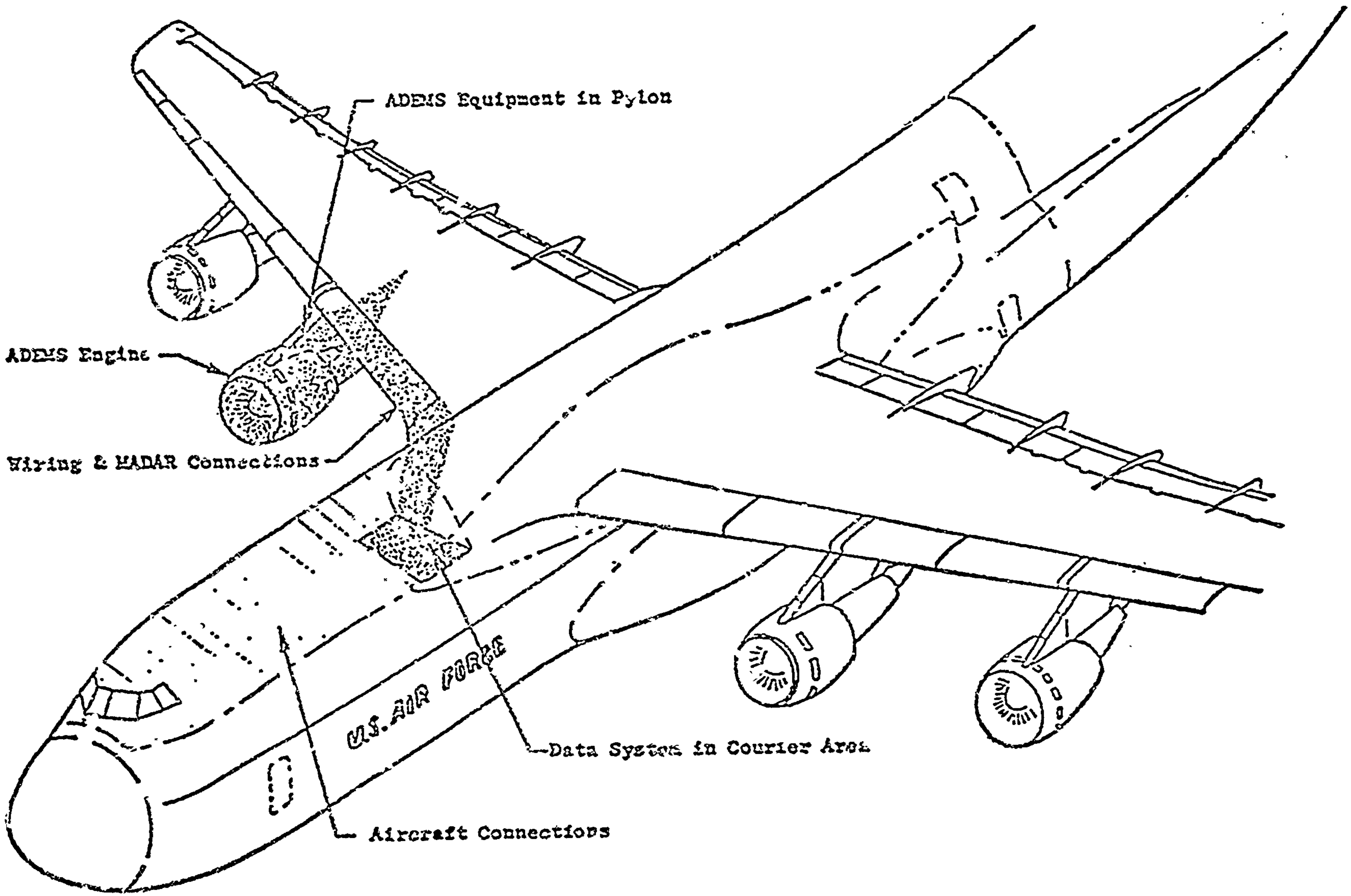
- FOD/DOD - Fan
- FOD/DOD - Core
- Engine Vibration Exceedance
- Gearbox Vibration Exceedance
- Lube Contamination Exceedance
- Lube Supply Pressure, Low
- Lube Scavenge Temperature, High
- Lube Tank Quantity, Low
- T54 Overtemperature
- BETA Schedule Fault
- PLA Schedule Fault
- Stage 1 Turbine Blade Overtemperature

With the exception of the FOD alerts, the system will provide immediate data display of the parameter value of the detected fault. In addition, the air crew will be able to request data display, subsequent to takeoff, of available takeoff T54 margin.

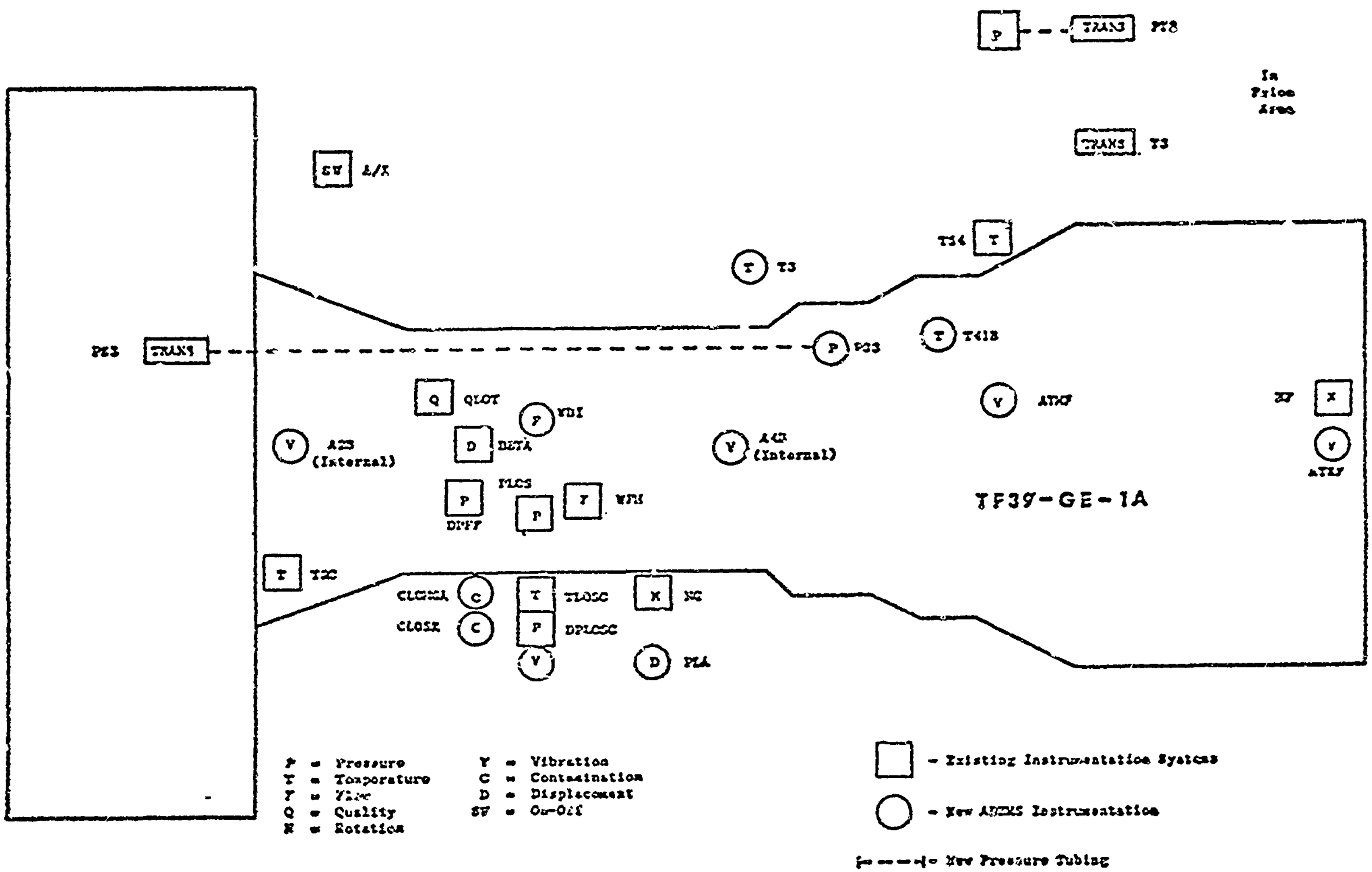
On-board recording of appropriate data will provide ground processing capability for indication of the following:

- Engine Vibration Trends
- Gearbox Vibration Trends
- Lube Contamination Trends
- Lube Supply Pressure Trends
- Lube Scavenge Temperature Trends
- Lube Tank Quantity Trends
- Operational Hours/Number of Takeoffs Until T54 Margin = 0 (Hot Day)
- BETA Schedule Delta Trends
- PLA Schedule Delta Trends
- Stage 1 Turbine Blade Temperature Trends
- T54 Harness Fault

A contract was awarded to the General Electric Co. in Feb 1976 and the design and definition of the system and hardware along with procurement, fabrication, and assembly of system hardware has been initiated.



ADEMS II/C5A INTERFACE



Location of ADEMS II Sensors on Engine.

	ADEMS Engine Transducer	MADAR/ Aircraft Signal
No. 2 Bearing-Internal Accelerometer	X	-
No. 4 Bearing-Internal Probe Accel.	X	-
Turbine Midframe Accelerometer	X	-
Turbine Rear Frame Acceleometer	X	-
Gearbox Accelerometer	X	-
Mag. Chip Detector-Gearbox	X	-
Lube Debris-Scavenge Return	X	-
Lube Supply Pressure	-	X
Lube Scavenge Temperature	-	X
Lube Tank Quantity	-	X
Scavenge Filter Diff. Pressure	-	X
Stage 1 Turbine Blade Pyrometer	X	-
Beta Position	-	X
PLA Position	X	-
Fan Speed	-	X
Core Speed	-	X
Mach No.	-	X
Altitude	-	X
Squat Switch	-	X
Fuel Flow	-	X
T_O	-	X
P_2	X	-
T_{2C}	-	X
P_{S3}	X	-
T_3	X	-
T_{54}	-	X
EPR	-	X
8th Stg. Bleed Flow	X	-
A/1 Valve Position	-	X

ADEMS II

DATA SCANNING/ACQUISITION/DISPLAY

- TAKE-OFF MODE
  - AT HIGH, ESSENTIALLY STABLE T54 - RECORD TWO/THREE COMPLETE DATA POINTS, TWO SECOND INTERVALS, EXCEPT VIBES.
  - ALTERNATE TAKE-OFFS, #2 BRG. OR #4 BRG. 1/REV. SIGNAL RECORDED AT 1/4 SECOND INTERVALS.
  - BITE AND CAL. CHECKS EVERY SIX SECONDS. NO VIBE BITE CHECKS.
  - CREW ALERT LIMITED TO:
    - T54 OVER-TEMPERATURE.
    - FOD/DOD.
    - LOW LUBE OIL PRESSURE.
  - PRE/POST-FAILURE EVENT RECORDING.

ADEMS II

DATA SCANNING/ACQUISITION/DISPLAY

- NORMAL MODE
  - COMPLETE DATA POINT ALL PARAMETERS EVERY SIX SECONDS.
    - DATA POINT DERIVED AS MEDIAN OF SEVEN SCANS EACH PARAMETER.
  - BITE CHECK MAJORITY OF DATA CHANNELS EACH SIX SECOND SCAN CYCLE.
  - CALIBRATION AUTO-ADJUST (A/D CONV.) EACH SIX SECOND SCAN CYCLE.
  - DETECTED LIMIT EXCEEDANCE VALIDATED BY RE-CHECK PRIOR TO CREW ALERT
    - WILL DISPLAY TWO EXCEEDANCES WITH PARAMETER VALUES.
  - PRE/POST FAILURE EVENT BUFFER DUMP TO MAGNETIC TAPE.
    - ONE (1) MINUTE PRE & ONE (1) MINUTE POST.
  - AT CRUISE, TWO/THREE DATA POINTS ALL PARAMETERS EVERY TWENTY (20) MINUTES RECORDED FOR GROUND TREND PROCESSING.
    - KEY PARAMETER CHECKS TO ASSURE ENGINE CONDITIONS STABLE PRIOR TO RECORDING.

ADEMS II

MAJOR MILESTONES

CONTRACT DATE	2/20/76	
SYSTEM & HDWR DESIGN COMPL.	9/30/76	
MOD. ENGINE HDWR AT SAALC	12/15/76	
AIRBORNE SYSTEM PROGRAMMING COMPL.	12/31/76	
ENGINE AT GE EVENDALE	2/15/77	
DATA SYSTEM TESTING COMPL.	5/31/77	
AIRCRAFT, MOD. KIT AT SAALC	7/15/77	
ENGINE/DATA SYSTEM TESTING COMPL.	7/15/77	
EQUIPMENT INSTALLATION AT ALTUS		
START	9/1/77	
CHECK-OUT COMPL.	10/31/77	
<u>FLIGHT EVALUATION</u>		
START	11/1/77	* PRESENT STATUS
COMPL.	4/30/79	
FINAL REPORT	7/31/79	

ADEMS II STATUS

- AIRCRAFT PRESENTLY FLYING AT DOVER AFB, DEL.
- FLIGHT EVALUATION WILL CONTINUE THROUGH MAY 1979
- FINAL REPORTS AND LESSONS LEARNED ARE DUE BY JULY 1979

PERFORMANCE TRENDING

BY

W. PASELA

NAPC, TRENTON, N. J.

AV 443-7262

HIGHLIGHTS

The purpose is to replace MOT (time) overhaul with on-condition maintenance based on an Engine Analytical Engine Program (EAMP). Remove engines only for FOD, significant malfunction or performance degradation based on isolation of component or module. The development trending is being done on an ICEMS equipped TF30-412A in a test cell including altitude and air speed conditions. Each channel is read 5 times per second for 10 seconds. The average is calculated and checked for deviation. The performance delta is calculated. The averages, delta and engine time are stored in the memory. Good indicators of engine condition are rotor speed match (RPM ratio between high and low speed rotors), EGT vs high rotor speed, and fuel flow over burner pressure vs high rotor speed. Design out the fat leave the man in the loop. Develop the system for the one who is going to use it. Recorded data has much unwanted high frequency noise. ICEMS data shows as much as 6% in RPM. Effective use of data depends repeatability.

TEST CELL ENGINE TREND EXPERIENCE AND A PROGRAM TO EXTEND THE PERFORMANCE TRENDING CONCEPT TO THE INFLIGHT REGIME UTILIZING THE EICMS - EQUIPPED A-7 AIRCRAFT

EAMP CONCEPT

ELIMINATE MOT (OVERHAUL)

REMOVE ONLY FOR CAUSE:

- FOD
- SIGNIFICANT MALFUNCTION
- PERFORMANCE DEGRADATION

ISOLATE MALFUNCTION/DEGRADATION TO COMPONENT/MODULE LEVEL - REPAIR ONLY WHAT IS NECESSARY

NAVY NEEDS

EFFICIENT, EFFECTIVE FLIGHTLINE MONITORING CAPABILITY WITH DATA REDUCTION AND INTERPRETATION CAPABILITY AT THE SQUADRON LEVEL.

CENTRALIZING DATA ANALYSIS NAVY-WIDE NOT PRACTICAL. COMMUNICATIONS LINKS TO CENTRAL ANALYSIS CENTER ARE NON-EXISTENT AND WOULD BE VIRTUALLY IMPOSSIBLE TO SET UP.

OUR AIRFIELDS <u>MOVE</u>

COMMUNICATIONS COULD COMPROMISE SECURITY PINPOINTING CARRIER LOCATION.

MOST EFFECTIVE MEANS AT PRESENT TO ISOLATE FAULTS TO COMPONENT/ MODULE,

LEVEL IS BY GAS PATH ANALYSIS TECHNIQUE AND/OR PARAMETRIC TRENDING.

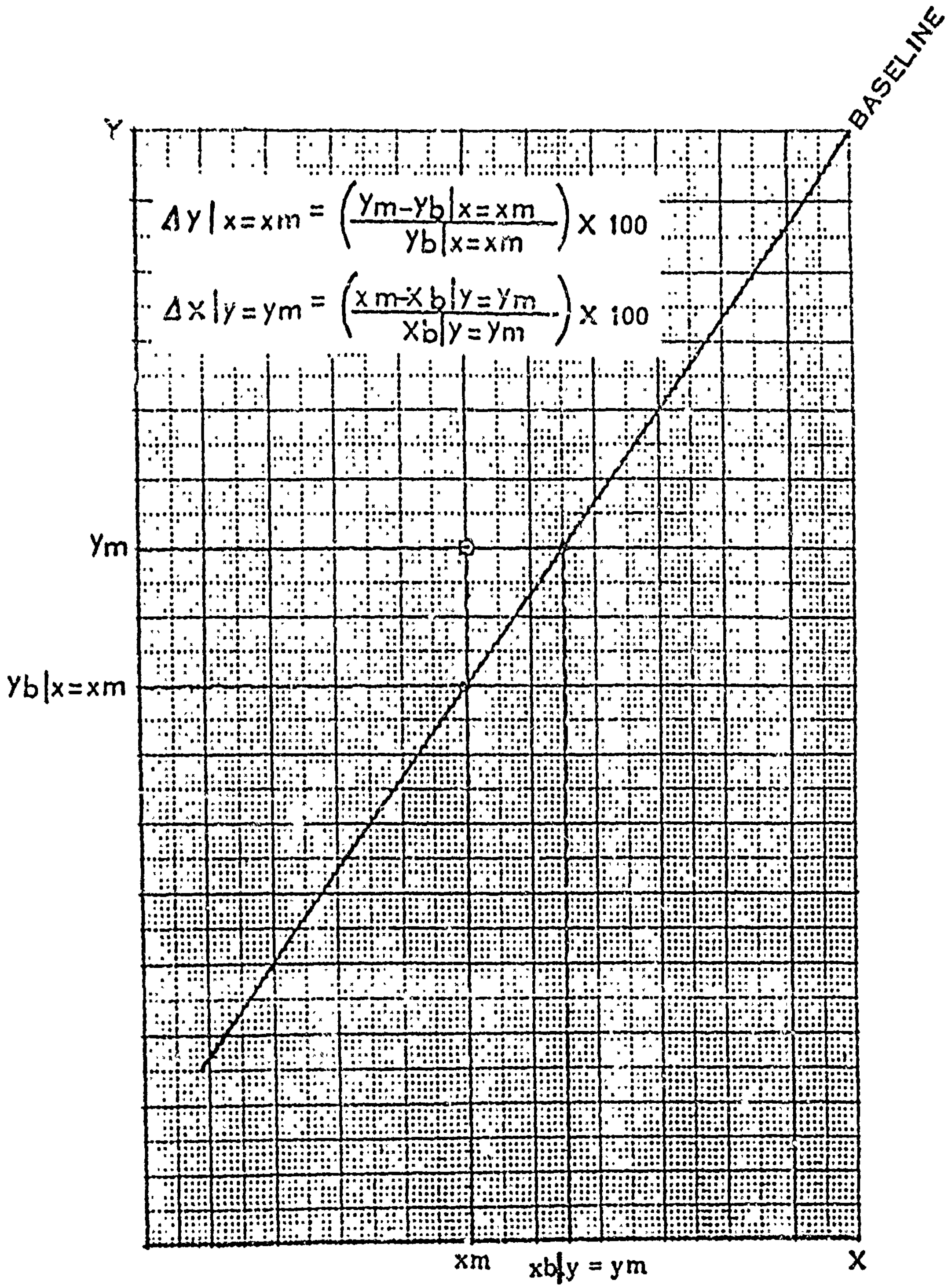
PARAMETRIC TRENDING IS SIMPLE ENOUGH TO BE UTILIZED BY FIELD MAINTENANCE PERSONNEL.

AIR FORCE ALREADY USES THIS TECHNIQUE.

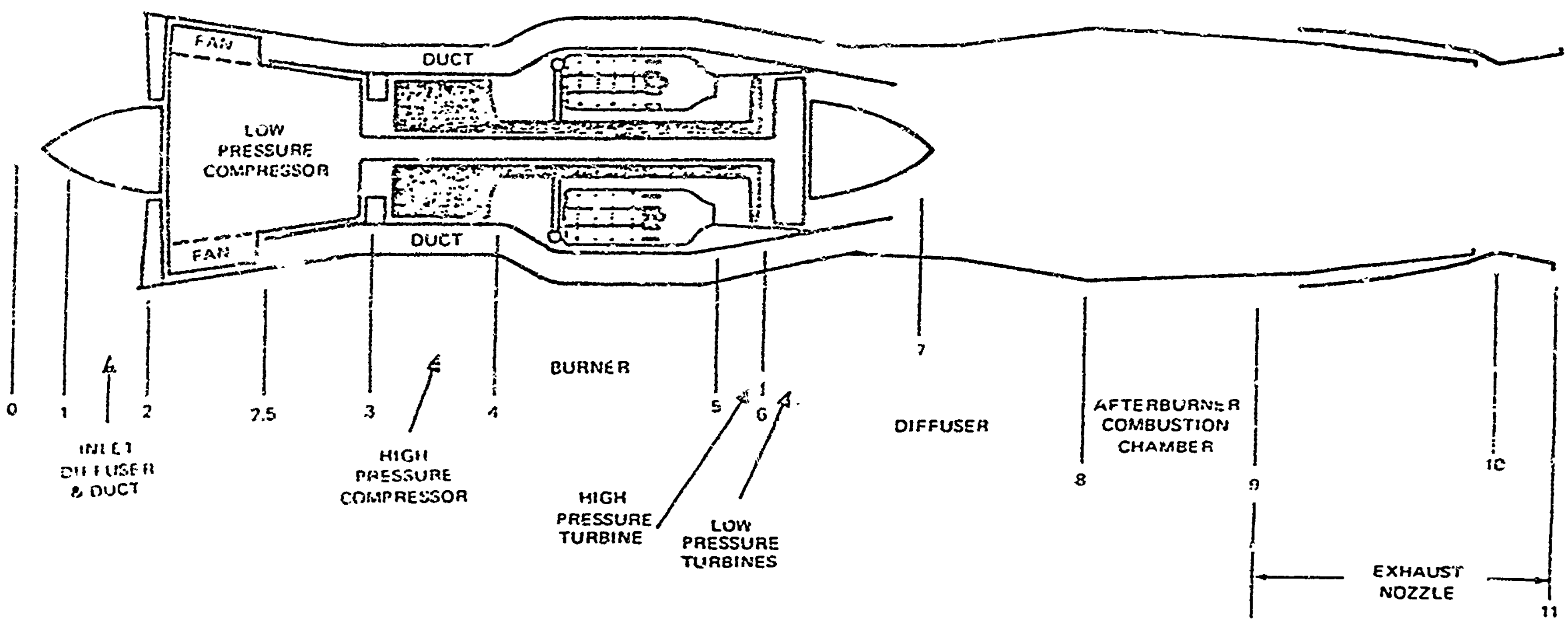
TEST CELL DATA FROM A TF30-P-412A ENGINE APPEARS IN THE FOLLOWING VIEWGRAPHS.

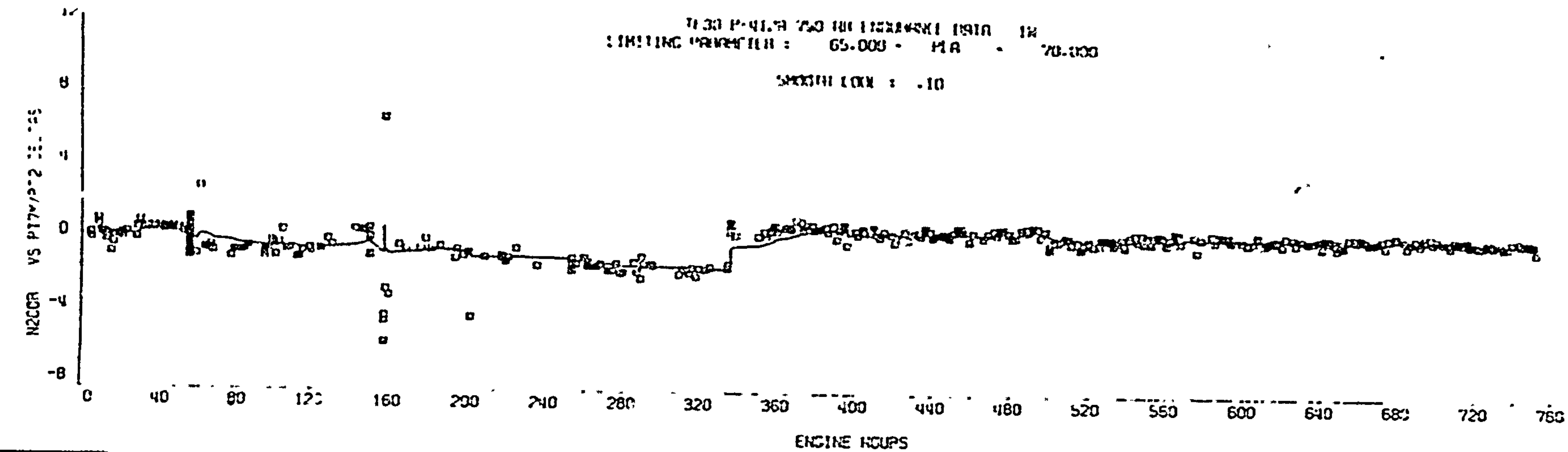
RATHER THAN TREND PARAMETRIC VALUES, THE DELTAS OR PERCENTAGE SHIFTS OF ENGINEERING RELATIONSHIPS WERE TRENDED.

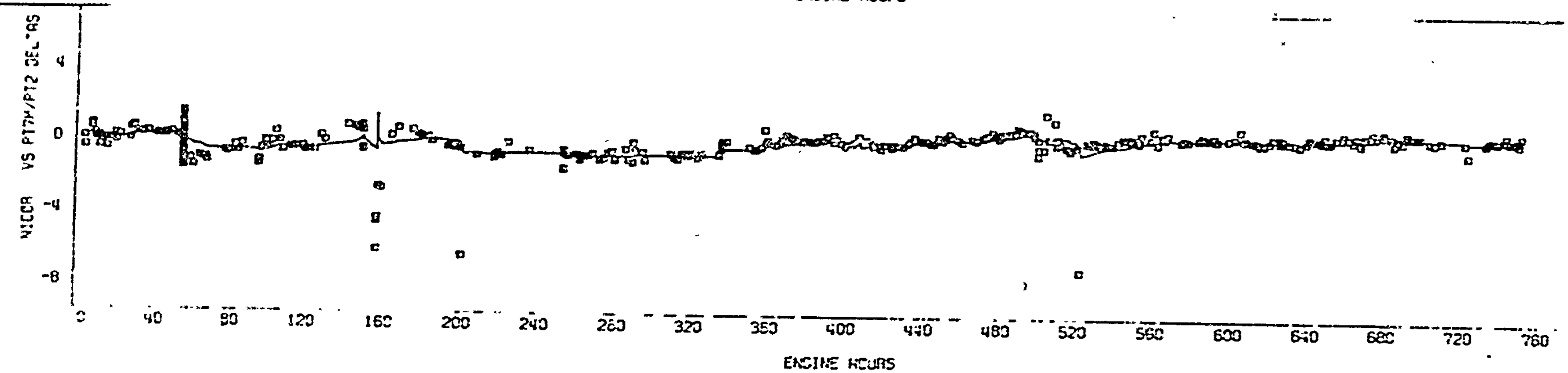
GENERAL DEFINITION OF Δ

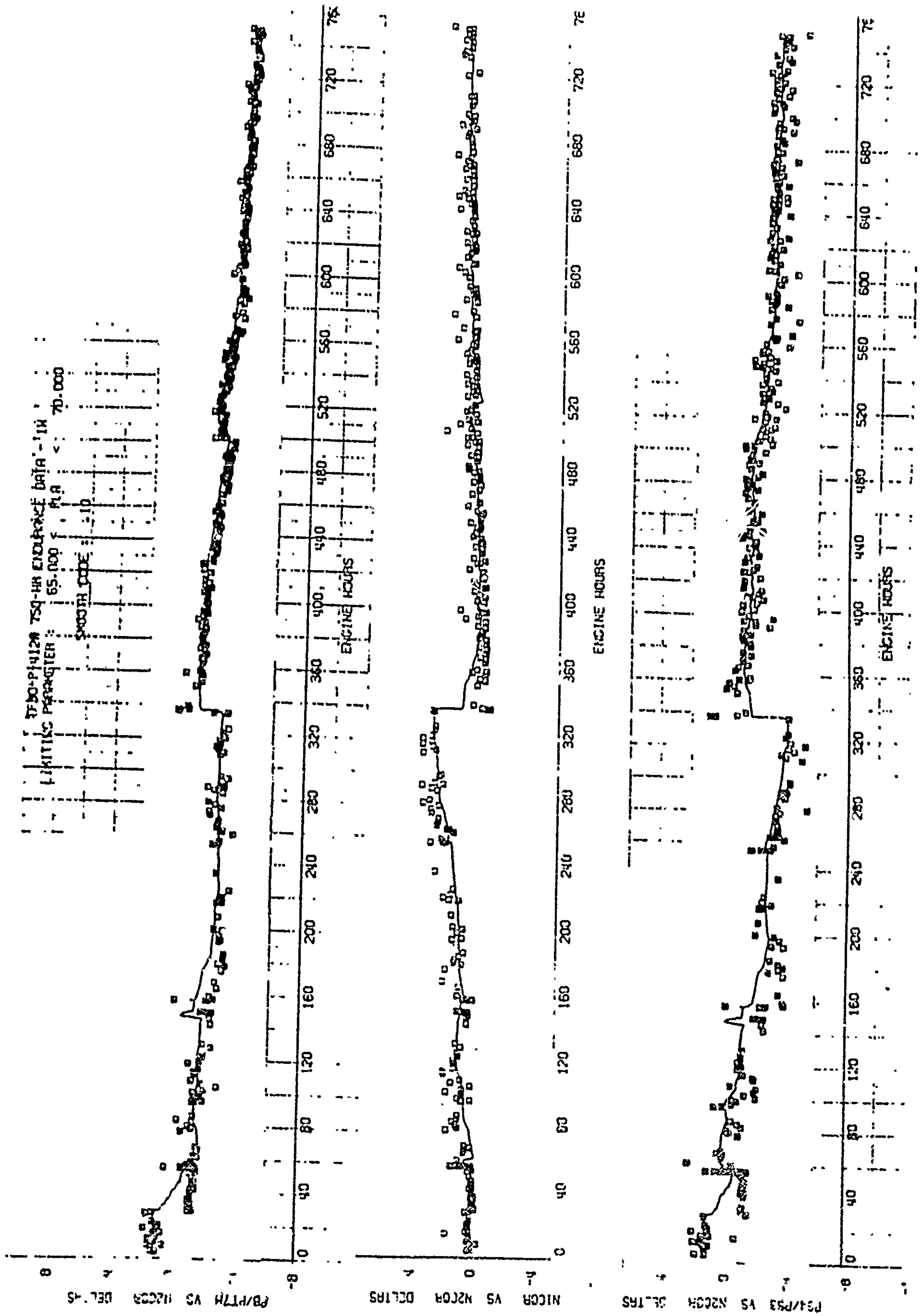


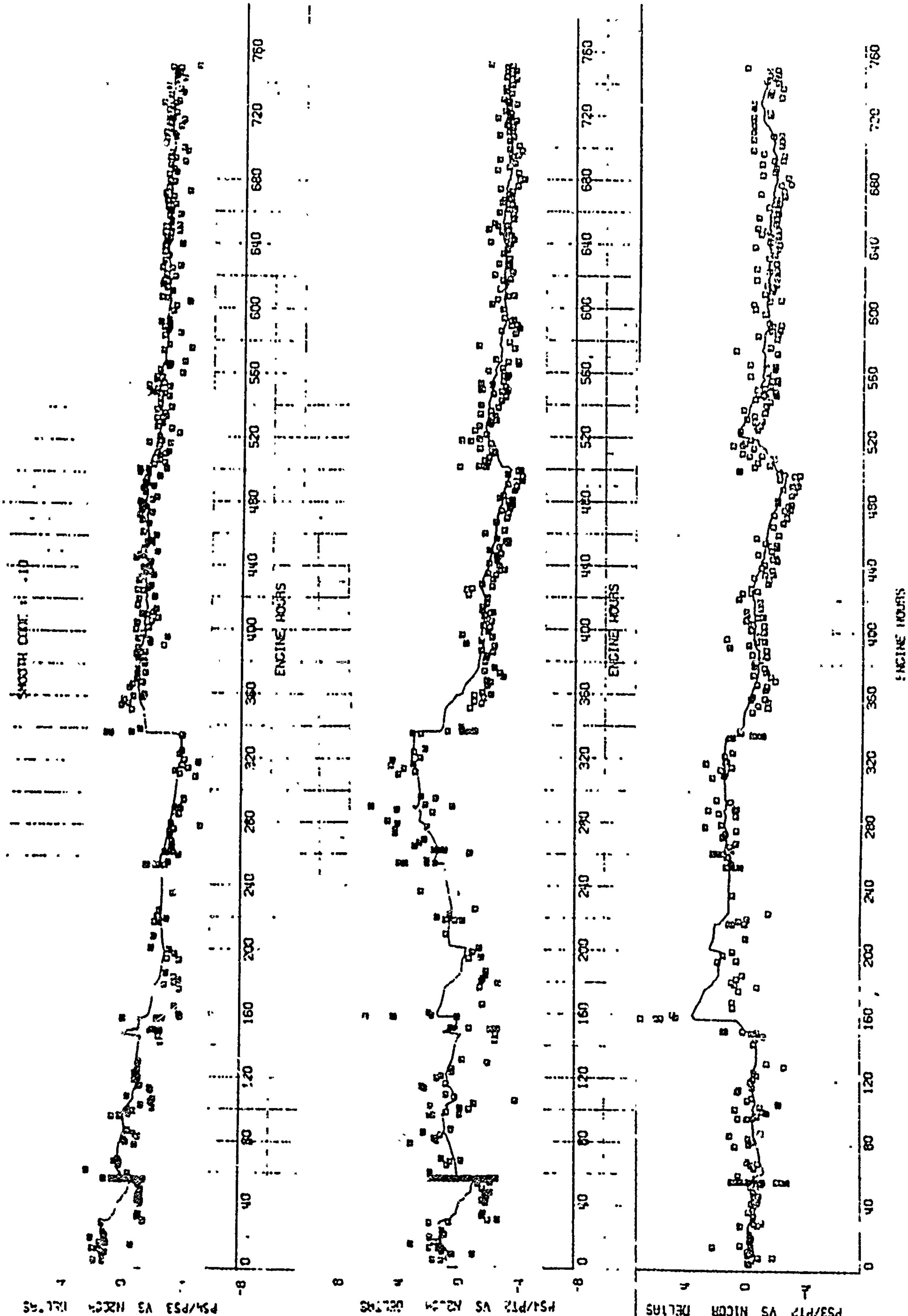
STATION IDENTIFICATION (U)

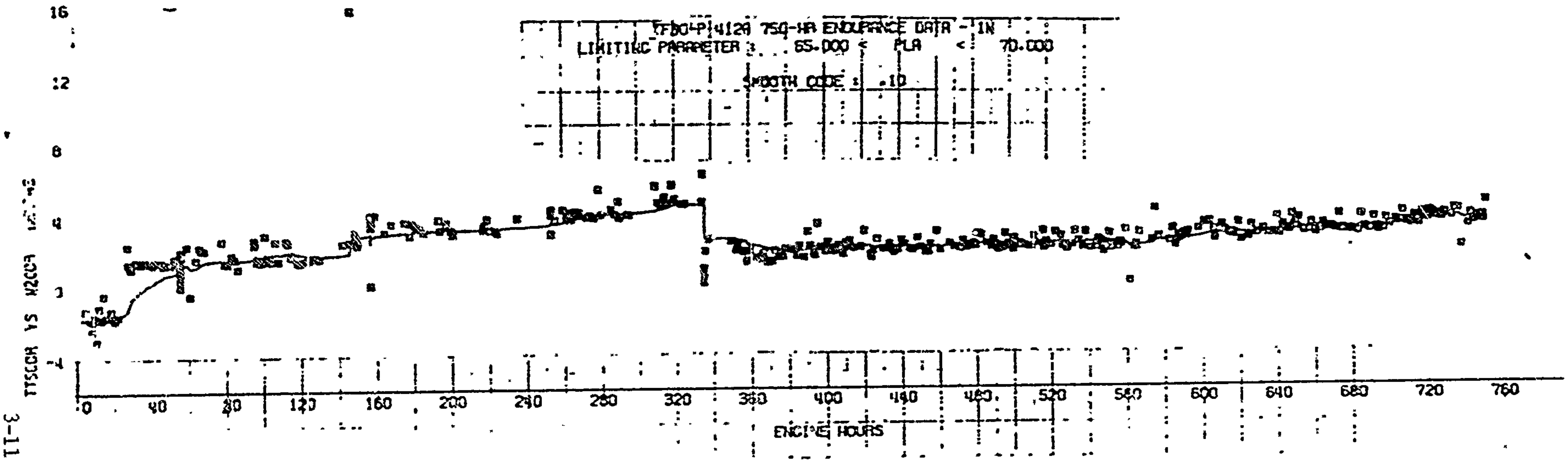


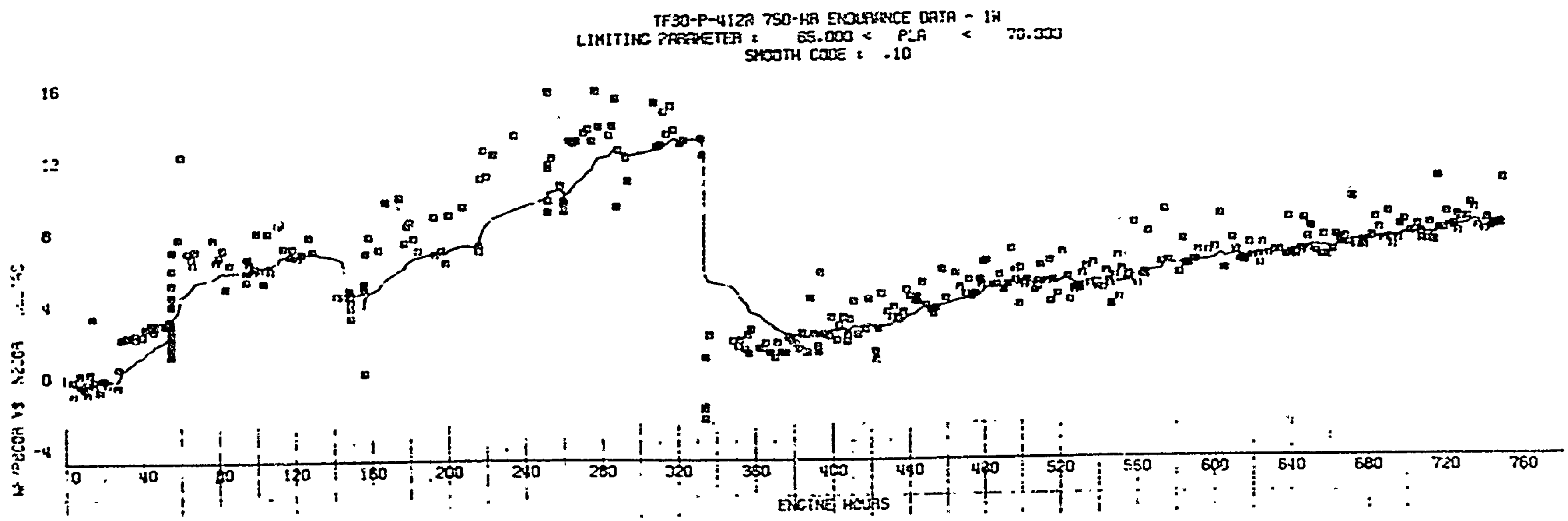

ENGINE HOURS


ENGINE HOURS


ENGINE HOURS
ENGINE HOURS
ENGINE HOURS


PS4/PS3 VS N2C24 DELTAS
PS4/PT2 VS N2C24 DELTAS
PS3/PT2 VS N1C0R DELTAS
ENGINE HOURS
SMOOTH CODE = 10


TF30-P-412A 750-HR ENDURANCE DATA - 1N
LIMITING PARAMETER : 65.000 < PLA < 70.000
SMOOTH CODE : .10
16
12
8
4
0
-4
TTSCCH VS N2CCA
0
40
80
120
160
200
240
280
320
360
400
440
480
520
560
600
640
680
720
760
ENGINE HOURS


TF30-P-412A 750-HR ENDURANCE DATA - 1N
LIMITING PARAMETER : 65.000 < PLA < 70.000
SMOOTH CODE : .10
16
12
8
4
0
-4
0
40
80
120
160
200
240
280
320
360
400
440
480
520
560
600
640
680
720
760
ENGINE HOURS

TF30-P-412/414
PERFORMANCE MONITORING CURVE PAIRS FOR AUTOMATIC HEALTH MONITORING

1	T_{T7M}/θ_2 vs. P_{T7M}/P_{T2}
2	$W_{fe}/\delta_2\theta_2^{.68}$ vs. P_{T7M}/P_{T2}
3	T_{T5}/θ_2 vs. P_{T7M}/P_{T2}
4	$N_1/\ \theta_2$ vs. P_{T7M}/P_{T2}
5	$N_2/\ \theta_2$ vs. P_{T7M}/P_{T2}
6	$\frac{W_A\ \ \theta_2}{\delta_2}$ vs. P_{T7M}/P_{T2}
7	P_b/P_{T7M} vs. P_{T7M}/P_{T2}
8	$N_1/\sqrt{\theta_2}$ vs. $N_2/\sqrt{\theta_2}$
9	$W_{fe}/\delta_2\theta_2^{.68}$ vs. $N_2/\sqrt{\theta_2}$
10	P_b/P_{T7M} vs. $N_2/\sqrt{\theta_2}$
11	P_{S4}/P_{T2} vs. $N_2/\sqrt{\theta_2}$
12	P_{S4}/P_{S3} vs. $N_2/\sqrt{\theta_2}$
13	$W_{fe}/P_b\ 2^{.68}$ vs. $N_2/\sqrt{\theta_2}$
14	T_{T5}/θ_2 vs. $N_2/\sqrt{\theta_2}$
15	$W_{fe}/F_N\theta^{.68}$ (TSFC) vs. F_N/δ_2
16	$N_2/\sqrt{\theta_2}$ vs. F_N/δ_2
17	T_{T5}/θ_2 vs. F_N/δ_2
18	P_{T7M}/P_{T2} vs. F_N/δ_2
19	P_{S3}/P_{T2} vs. $N_1/\sqrt{\theta_2}$
20	$\frac{W_A/\ \theta_2}{\delta_2}$ vs. $N_1/\sqrt{\theta_2}$
21	$W_{fe}/\delta_2\theta_2^{.68}$ vs. T_5/θ_2

HEALTH INDICATORS

MANY PARAMETERS RELATIVELY INSENSITIVE TO STABILITY.

Δ SCATTER BAND ±1/4% AFTER 30 SEC STABILIZATION.

"WINDOW" FOR TRENDING NEED NOT BE TOO RESTRICTED.

IDENTICAL TRENDS WITH ENGINE AGE AND USAGE WERE VERIFIED ON OPERATIONAL AIRCRAFT AT NELLIS AFB DURING AIMVAL/ACEVAL INVESTIGATION. THESE MEASUREMENTS, HOWEVER, WERE TAKEN DURING GROUND RUNUP.

PRIOR TREND WORK DONE WITH GROUND-BASED TEST DATA.

NEXT ATTEMPT IS TO UTILIZE IN-FLIGHT GENERATED DATA FROM A-7 IECMS TO DETERMINE IF SIMILAR MEANINGFUL TRENDS CAN BE GENERATED.

RELATIONSHIPS BEING INVESTIGATED ON THE TF41-A-2 (EICMS) ENGINES

$\delta P_{T1} = \frac{P_{T1}\text{"HgA}}{29.92}$ $\theta_{T1} = (T_1{}^{\circ}F + 459.7)/518.7$

a. $NL/\sqrt{\theta_{T1}}$ vs. $NH/\sqrt{\theta_{T1}}$
b. $Ps3/P_{T1}$ vs. $NH/\sqrt{\theta_{T1}}$
c. $T3/T1$ vs. $NH/\sqrt{\theta_{T1}}$
d. $Ps3/P5.1$ vs. $NH/\sqrt{\theta_{T1}}$
e. $T5.1/\theta^{.8788}$ vs. $NH/\sqrt{\theta_{T1}}$
f. $Wf/\delta P_{T1}\sqrt{\theta_{T1}}$ vs. $NH/\sqrt{\theta_{T1}}$
g. $Wf/Ps3\sqrt{\theta_{T1}}$ vs. $NH/\sqrt{\theta_{T1}}$
h. $P_{T2.1}/P_{T1}$ vs. $NL/\sqrt{\theta_{T1}}$
i. $Ps3/P_{5.1}$ vs. $NL/\sqrt{\theta_{T1}}$
j. $T_{5.1}/\theta^{.8788}$ vs. $P5.1/P_{T1}$
k. $Wf/\delta P_{T1}\sqrt{\theta_{T1}}$ vs. $P5.1/P_{T1}$
l. $NL/\sqrt{\theta_{T1}}$ vs. $P5.1/P_{T1}$
m. $NH/\sqrt{\theta_{T1}}$ vs. $P5.1/P_{T1}$
n. $Ps3/P5.1$ vs. $P5.1/P_{T1}$
o. $T3$ vs. $Ps3/P_{T1}$
p. IGV vs. NL
q. $P5.1/P_{T1}$ vs. $T5.1$

TYPICAL EICMS DATA FRAME

TIME	T5	NH	NL	PS3	T3	PT2.1	WF	IGV	PLA
6.7	446.2	66.3	35.3	39.1	303.3	16.6	944.0	36.3	18.5
	447.1	65.3	34.5	37.2	297.9	16.7	922.9	36.3	18.5
	448.0	64.1	33.9	35.0	291.7	16.6	928.2	36.3	18.5
	447.1	63.3	33.1	35.6	287.2	16.5	927.9	36.5	18.4
6.9	447.1	62.7	32.4	34.8	283.6	16.4	933.5	36.3	18.5
	447.1	61.9	31.7	34.4	279.1	16.4	938.7	36.3	18.5
	448.0	61.3	31.3	32.8	274.6	16.4	938.7	36.3	18.5
	449.7	60.7	30.8	33.2	271.9	16.3	944.0	36.3	18.5
7.2	451.5	60.3	30.3	32.5	268.3	16.3	954.0	36.3	18.5
	453.2	59.9	30.0	32.5	265.6	16.4	954.6	36.3	18.5
	453.2	59.5	29.6	32.1	262.0	16.1	956.0	36.3	18.5
	455.9	58.9	29.3	31.7	258.4	16.2	970.4	36.3	18.5
7.5	457.6	58.7	29.0	31.3	254.8	16.3	965.1	36.3	18.5
	459.4	58.5	28.8	31.3	252.1	16.3	970.4	36.3	18.5
	460.3	58.2	28.6	31.3	249.4	16.2	975.7	36.3	18.5
	462.0	58.0	28.4	30.9	247.6	16.1	975.7	36.3	18.5

SMP	T5	NH	NL	PS3	T3	PT2.1	WF	IGV	PLA	P5.1	T1	ALT	MN
1	447.1	64.7	34.2	36.9	295.0	16.6	929.5	36.4	18.5	20.6	35.3	*******	0.0
2	448.0	61.0	31.6	33.8	277.3	16.4	938.7	36.3	18.5	20.7	35.1	*******	0.0
3	453.5	59.7	29.8	32.2	263.6	16.3	958.5	36.3	18.5	20.6	34.8	*******	0.2
4	459.8	58.3	28.7	31.2	250.9	16.1	971.7	36.3	18.5	19.2	35.1	*******	0.2

CONDITION: CONDITIONAL TIME: 7.1

SMP	T5	NH	NL	PS3	T3	PT2.1	WF	IGV	PLA	P5.1	T1	ALT	MN
A	452.1	61.1	31.1	33.5	271.7	16.3	949.6	36.3	18.5	20.3	35.0	*******	0.1

DATA MANAGEMENT

KEY TO EFFECTIVE, MEANINGFUL MONITORING AND DIAGNOSTICS.

PRESENT SYSTEMS INUNDATE THE OPERATOR WITH DATA AND VIRTUALLY REQUIRE ENGINEERS TO INTERPRET.

SYSTEM OUTPUTS MUST BE INTERPRETABLE BY REGULAR LINE MAINTENANCE PERSONNEL.

DESIGN OUT THE FAT

TREND DATA MANAGEMENT USED FOR TF41 IECMS DATA

If reason bit is proper for trending (Stable) and two or more samples are valid, do Data stability, validity check.

Is PLA Stable? $\pm 0.5^\circ$

Is $10 \leq$ PLA ≤ 75

If yes:

Is NH stable ? $\pm$ 1%

Is 50% $\leq$ NH $\leq$ 100%

If yes:

Is NL stable ? $\pm$ 1%

Is 25% $\leq$ NL $\leq$ 100%

If yes:

Is T_5 stable ? $\pm 5^\circ$

Is $T_5 \leq 600^\circ$

If yes:

Is W_f stable? $\pm$ 25#

If so, perform averaging reduction and output one data line to use in trending.

Performance deltas calculated from averages.

DATA MANAGEMENT TECHNIQUE UTILIZED ON THE TF30-P-412

TREND DATA

- READ EACH CHANNEL 5 TIMES PER SECOND FOR 2 SECONDS
- CALCULATE PARAMETER AVERAGE
- CHECK FOR STANDARD DEVIATION EXCEEDANCE
- CALCULATE PERFORMANCE DELTAS USING CHANNEL AVERAGES
- STORE IN MEMORY <u>ONLY</u> CHANNEL AVERAGES PLUS ENGINE TIME AND PERFORMANCE DELTAS

TF30- TECHNIQUE MORE EFFICIENT FOR DATA STORAGE

MINIMIZES MEMORY CAPACITY REQUIREMENTS FOR ON-BOARD SYSTEM

FLIGHT HARDWARE CAN BE SMALLER, LIGHTER

HAND-PLOTTING OF TREND DELTAS COULD BE UTILIZED AT LINE LEVEL IF GROUND STATION CAPACITY IS LIMITED

ENGINE ANALYTICAL MAINTENANCE PROGRAM

BY

L. DOUBLEDAY

NASA WASH DC

AV 222 9125

HIGHLIGHTS

The engine analytical maintenance program (EAMP) is based on the identification of design deficiencies and reliability improvement modifications. Preventive maintenance maintains reliability, improves economy, and insures safety. If not, a design deficiency exists. The Navy has 20399 engines, 12243 installed, 8096 uninstalled, balance in transit. A manual log of data is in the engine record. One complication for EAMP is that new modules/parts in an engine change its signature.

THE ENGINE ANALYTICAL MAINTENANCE PROGRAM

EAMP

SUMMARY

NAVAL AVIATION MAINTENANCE PROGRAMS

WILL UTILIZE RCM CONCEPTS

THROUGHOUT

THE

1980's

SCOPE

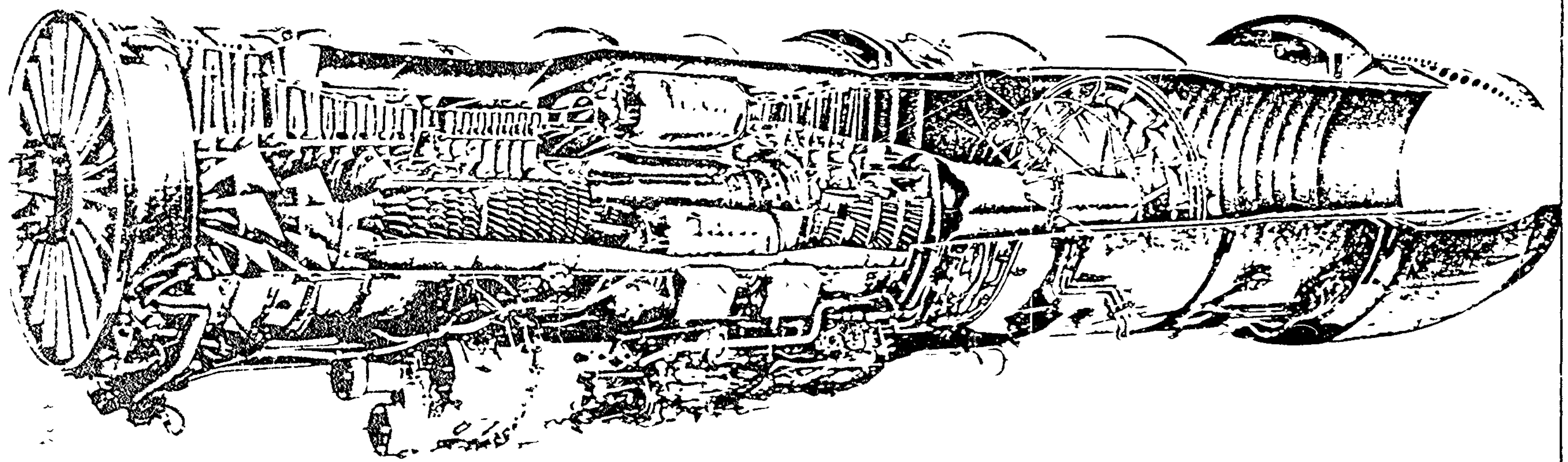
20,399 ENGINES

WORTH

3.825 BILLION DOLLARS

12,243 INSTALLED

8,096 UNINSTALLED



TF30-P-414
AFTERBURNING TURBOFAN ENGINE

10K + PARTS

PRE - EAMP

- SCHEDULED MAINTENANCE
  - MOST T/M/S REQUIRE VISUAL HOT SECTION INSPECTION EVERY X ENGINE HOURS
  - OVERHAUL REQUIRED EACH TIME "MOT" REACHED
  - SAMPLE ENGINES AT "MILESTONES" REACHING TOWARD HIGHER "MOT"

PRE - EAMP PROGRAM CONCEPT

- OVERHAUL JUST BEFORE WEAR OUT
- PRECLUDE PREMATURE FAILURES THRU 100% PERIODIC INSPECTIONS

OVERHAUL DEFINITION:

"RESTORATION OF ENGINE TO LIKE NEW CONDITION BY REPLACEMENT, REPAIR AND INCORPORATION OF LATEST TD's WHEREBY THEY ARE THEORETICALLY CAPABLE OF OPERATING TO MOT".

PRESENT PROGRAM

- UNSCHEDULED MAINTENANCE
  - MALFUNCTION DETERMINED BY O-LEVEL
  - REPAIRED AT MAINTENANCE LEVEL THAT ENSURES OPTIMUM ECONOMIC USE OF RESOURCES

PRESENT PROGRAM

MAINTENANCE LEVELS

O - R/R SOME ACCESSORIES/ENGINE

I_3 - R/R ACCESSORIES/HOT SECTION

I_2 - TURBINE REPLACEMENT

I_1 (CER) - FAN/COMPRESSOR REPLACEMENT

D - ENGINE OVERHAUL/ACCESSORY - FAN - COMPRESSOR - GEARBOX - TURBINE REPAIR

IMA PROCESSING

749

YR	RCVD	RFI	BCM	CK-OK	INSP
74	6487	2653	2424	233	1177
75	7819	3824	2469	267	1259
76	6037	2802	2267	192	776
77	6257	2878	2276	210	893

PRESENT EXPERIENCE CONCLUSIONS

- FAILURE RATE HIGH
- OVERHAUL NOT INCREASING DURABILITY SIGNIFICANTLY
- ENGINE WEAR OUT NOT SUPPORTED
- SHOP CAPACITY INADEQUATE
- MAINTENANCE PROGRAM NOT BEING ACCOMPLISHED

COMPARISON OF REPAIR vs OVERHAUL

			EXPECTED LIFE OF ENGINE BEFORE NEXT REMOVAL (HRS)				
			AFTER OVHL	AFTER REPAIR (% MOT)			
ENGINE	ACFT	MOT		0-.25	.26-.50	.51-.75	.76-1.00
T400-CP(P)	H-1	2000	471	545	354	430	651
T53-L-13B	H-1	1800	618	615	871	486	375
T56-A-426(P)	E-2	6000	347	323	233	214	176
T58-GE-10	H-46	2400	194	209	235	224	178
T58-GE-8B/F	H-2	2400	432	433	291	275	638
T64-GE-413	H-53	2000	491	483	601	437	585
F402-RR	AV-8	1000	197	220	123	157	207
J52-P-408	A-4	2000	216	219	157	118	206
J60-P-3A	T-39	3000	321	261	306	254	406
J79-GE-10	F-4	2400	208	216	167	143	130
J85-GE-4	T-2C	3600	353	325	248	235	248
TF30-P-408	A-7B	1000	207	231	150	215	158
TF34	S-3	4000	179	167	136	136	140
TF41	A-7E	1000	148	116	67	72	72

GENERAL NEEDS

ISSUE AND MAINTAIN A PROGRAM DOCUMENT THAT WILL –

- COVER THE OVERALL PROGRAM
- IDENTIFY RESPONSIBILITIES
- ESTABLISH GOALS
- PROVIDE STATUS AND DIRECTION
- BUILD AN IN-HOUSE TECHNICAL CAPABILITY

ISSUED – 20 SEP 1977

REVISED – 28 FEB 1978

PROGRAM FEATURES

DROP –

- ENGINE OVERHAUL
- MOT ON ENGINES
- MOT ON MODULES/COMPONENTS

EFFECTIVE – 1 OCT 1978

PROGRAM FEATURES

CONTROL THE PROGRAM THRU -

- MAINTENANCE PLANS
- TIMELY STATUS VISIBILITY OF ALL NON RFI ENGINES
- PREVENTIVE MAINTENANCE
- TIME COMPLIANCE CHANGES
- LIFE LIMITED PARTS MANAGEMENT

PROGRAM FEATURES

PROGRAM STATUS AND DIRECTION THRU

- TRACKING RATES
  - ENGINE REMOVALS
  - SCHED MAINT MAN HOURS
  - PREVENTIVE ENGINE REMOVALS

PER 1000 FLT HRS

DURABILITY TRACKING/INCENTIVES

- EXPECTED LIFE FOR T/M/S
  - OVERALL
  - BY SHCP

PROGRAM FEATURES

SHOP STATUS KNOWLEDGE THRU

- ENGINES IN CUSTODY
- ENGINES PRODUCED
- ENGINES AWM/AWP
- ENGINES BCM'd

PROGRAM FEATURES

INCREASE TECHNICAL KNOWLEDGE THRU

- MSG-2 LOGIC
- ENGINE/COMPONENT FAILURE ANALYSIS
- THRESHOLD SAMPLING
- CONTINUOUS TEST STAND RUNNING
  - FLEET CONFIGURED
  - PROPOSED CHANGES
- DATA ANALYSIS

INTRODUCTION TO THE SEVENTH ANNUAL TRI-SERVICE DIAGNOSTIC CONFERENCE
DINNER PROGRAM
LT COL PETTIGREW, ASD/YZE

Gentlemen, let's move ahead by recognizing the Tri-Service Conference and why we are participating in this Seventh Annual Event. I would particularly like to recognize the individuals who have promoted this diagnostic activity over these years. Their actions have significantly furthered DOD engine diagnostic efforts through the interchange of information between the participating services. Tom Belrose from the Army, Keith Hamilton From the Air Force Aeropropulsion Lab at Wright-Patterson, and Andy Hess from the Navy basically put together the charter for this activity several years ago and have kept it going. I believe the information interchange has had a great payoff for the Department of Defense and I know first-hand that it helped in building the successful SAC Engine Condition Monitoring Program. Attendance at this Seventh meeting represents all areas of government, including NASA and the Office of the Secretary of Defense.

Understanding, evaluating, and applying diagnostic capability is a shared goal. A fundamental requirement for understanding is reflected in Voltair's thought, "If you would converse with me, define your words," we are in this meeting defining our words so that we can converse with one another. Assigning accepted standard meanings to words is a fundamental step in understanding.

Theoreticians use the scientific methods to establish theories. Proven theory is knowledge and we know that we must have knowledge in order to move forward. The people who really translate new knowledge into real world action are the engineers. They often make it work in spite of the imperfect knowledge that the theoreticians have been able to provide. The operators who turn the bolts and keep the airplane ready to fly use their ingenuity to overcome any imperfections in the engineer's work.

Will Rogers had a thought that I think we should consider for the moment. He said, "It's not what we know that hurts us, it's what we know that's <u>not</u> true." Earlier, I talked to Colonel Lowry. He mentioned an experience on his way down which reminded me of some words from Alice in Wonderland. "If you do not know where you are going, any road will get you there." A navigator might restate them as, "If you don't know your destination, one heading is as good as another." Pilots have a strong appreciation for navigator skills, especially their ability to direct them through thunderstorms. As you aircrew members know flying regulations do not allow flight in thunderstorms unless an operating radar is on board. Since pilots basically trust navigators, they will penetrate thunderstorms with their guidance. The navigator starts out with words to the effect that there is a way through the thunderstorm. The navigator will say, "I see a hole, turn to a heading zero-three-zero." After entering the thunderstorm on that heading it starts getting rough in a minute or two. The pilot becomes uneasy and says, "Nav what's the next heading?" The navigator will usually say "don't know, I can't see a thing, but heavy returns on the scope." The original heading was probably based on an apparent hole resulting from a shadow caused by a heavy return. The navigator's changing capability to see which way to go illustrates the importance of charting the total trip to your destination. In diagnostics, the destination or purpose often appears clear at the beginning of the program but becomes obscured as the development program progresses. This is especially true if the effort has not been based on overall system requirements including the life cycle cost considerations.

This diagnostics group, representing a cross-section of Department of Defense people associated with engine monitoring has the capability to look at the new and existing diagnostic capabilities, explore them, develop technologies and apply them. Most progress in the world has an informal base - notes on the back of napkins, and ideas of that kind. That's how this after dinner discussion idea came about. Keith Hamilton, Wade Stevenson, and I were having a cup of coffee in the cafeteria at Wright-Patterson one morning, brainstorming how we could make this Tri-Service Diagnostic Program more effective. We decided that the ideas of the people who will use these diagnostic techniques would be an essential input into the development cycle and would improve the operational capability of their propulsion systems. Learning from the experts how we might do better at meeting their operational capability appeared to be essential in better defining the problem. This program, conceived on the back of a napkin, has brought the responsible individuals from the Navy and Air Force here to share their understanding of how diagnostic techniques can be applied in support of their assigned weapon systems.

We are pleased to have with us tonight Lee Doubleday from NAVAIR, Jerry Schultheis from the Navy F-4 Service Dept, North Island, San Diego, Ca, Col Jim Streett, my ex-boss, from Hq SAC, Offutt AFB, Nebraska, Col Lowry from Hq MAC, Scott AFB, Ill, the world's greatest fighter pilot, Col Boyd Van Horn, from Hq TAC, Langley AFB, Va, and Col selectee Gillis from Hq ATC, Randolph AFB, Tx. These gentlemen own more engines than all the world's airlines and are responsible for keeping them ready to accomplish the DOD mission at any time and any place in the world. We have asked them to tell us tonight how diagnostic capability can be applied to help them carry out their mission.

At this time, I have a problem, one of these six distinguished gentlemen must be first. I know that Col Lowry has been airborne more than a year. He has more than 8,760 flying hours which is the number of clock-hours in a calendar year. That is significant, it could qualify him to be first. We have the world's greatest fighter pilot, Col Van Horn that is certainly an untouchable distinction. We also have the world's greatest engineer, Col Streett, positively an eminent qualification. However, since the Navy is our guest, we will solve the problem by asking Mr. Doubleday to begin tonight's program.

NAVAIR/NASC VIEW

BY

MR. LEE DOUBLEDAY

NAVAIR WASH DC

AV 222-9125

NAVAIR/NASC VIEW

MR LEE DOUBLEDAY

I really may not be highly qualified to talk on the subject of engine diagnostics. First of all I am not an operator. I am in the Maintenance and Logistics area. I gave you a little talk today about how we are trying to change the world of maintenance and logistics in the Nav- by using the Reliability Centered Maintenance Concept (RCM). I would really like to approach this from the standpoint of asking you if you can think of questions which you could ask me. It would be a lot easier than me trying to contrive something in my mind that I need from diagnostics.

I know I need diagnostics. I know it can do us all a lot of good by telling us more about our engines. There are a number of approaches to engine life management. We like our ICEMS on the A-7 aircraft but it is a little expensive and has some weight associated with it. One of the key things, and I think I mentioned it today, is that we think cycle count instead of clock time would be a better measure of our engines condition. I have seen lots of little devices that can count cycles. But I need the backing of our operator types to get approval to add that extra pound or two.

COL VAN HORN, (TAC) - Do you have a group or have you thought about organizing a group to do exactly that -- lay out the profiles for a cycle count versus hourly approach to engine usage.

MR. DOUBLEDAY, NAVY, yes we have a group under our component improvement program as does the Air Force. Since we share in the programs, we task the contractor to work those kinds of things. Our Navy Test Center does such things as define the typical mission, checking flight profiles, and trying to make those kinds of comparisons.

COL VAN HORN, Lee are you going out and talking to your pilots about how they fly your airplanes? We found out that if you don't you are going to get the wrong scenario. Find out how many times they do change the throttle. Put them in the simulator and make them do it and you will find out exactly.

WALT PASELA, NAPC, You mention that our test center had been counting these cycles. We did better than that. We did instrument an aircraft at Pax River and sent a pilot out to do typical mission and the function was telemetered back to ground. We saw a significant difference.

MR. DOUBLEDAY. The only problem is that it gets to be a sample of one and it would be great if we could really get it in the aircraft and get it across the board on several aircraft not just one at the test center. Get it out in operating squadrons where we are shooting a few landings on those carriers. That is where the wild stuff happens. We know that we have not been able to get the financial backing to get a little recorder pack on the aircraft other than our ICEMS which is out there on two squadrons doing it right now.

COL VAN HORN, TAC, I guess the only other recommendation I would have is to periodically follow up and update these mission profiles because they do change.

ANDY HESS, NAVAIR. A lot of systems are demonstrating or planning to demonstrate the capability for simulating life usage data. How are we going to get that life usage data? What is the most effective way to get that life data to some central location where somebody can keep track of it and make decisions using it?

MR. DOUBLEDAY. Okay, this is similar to a question the Colonel had this afternoon on automated log books, basically. Mr. Jim Evans is here from the TF30 world down in Norfolk where they are launching off into a new world of log books and the tracking of all the components within. One of the columns in the log books now reads: Time/Cycles. That is the basic hard copy type of thing. That information will be transcribed into the computer. We will eventually have that tracking going on for all of those components. This effort is still in the building phase and has a ways to go. We are starting to test it with the TF30 program. I don't know how long before we will have some answers.

JOHN GARNER, HQ 8 AF, What is a cycle?

MR. DOUBLEDAY. That is always a key question. We must have a correlation between some kind of cycle and some kind of damage.

MR. GARNER. I think we have got to lead out here to establish, with agreement between the services, a firm definition of a cycle. I have yet to find a single uniform definition of a cycle. Every contractor has their own. So we as users, I think it is up to us to say, "Hey look, Mr. Contractor, we are going to use this as our definition, and live with it. We then have a standard.

MR. DOUBLEDAY. I guess I don't fully agree with you on that point because it is going to tie in to the design of each individual piece of hardware and the minute you start putting a standard on it you are going to have an estimation just like we do with hours. I really see that there be a different ground rule or a different law as to what a cycle is. Unfortunately that is going to be tough and expensive to track. But I think that it is the only way we are going to get what we can out of that hardware. Else, we set a broad standard and come up with another estimation that fails to correlate with engine condition. That is the short coming I see in a standard cycle.

SMSGT POBANZ, HQ TAC, A master cycle in the J85 is a STOP, MAX POWER, back to STOP. Within that wide excursion there are partial cycles which are also damaging. The problem is apparently in determining what really constitutes a partial cycle and/to what extent it does damage and how do you count it?

MR. DOUBLEDAY. That is right. I think that Pratt and Whitney acknowledged that with the F100 you have got the events history recorder on the F100 and it has got a couple of counters-one that counts the mini cycle and one that counts the big ones.

SMSGT POBANZ. I think your point earlier was correct, the problems are going to be different with each model of engine and perhaps each type of application.

COL TALLMAN, AEDC. The application or usage is most important. The cycle on a S3A for the TF34 is not the same as the cycle on the A-10 for the TF34. Let's not tie it into an engine. Tie it into the mission usage.

MR. BELROSE. In the 1965-66 time frame, Howell Industries had under test in the Army a hot section analyzer (HSA) which was a little black box tied into the EGT system. Each time you start you would always get a cycle. Any time you went above 80% power you would get above the temperature where you would get a cycle. EGT above a certain temperature would cause the clock to run faster counting cycle per unit. When EGT went above 590 degrees, it would start clicking over very slowly on a different counter than when you got above 610 degrees. start clicking faster and go on until you got 650 degrees when it would really snap them off. This device recorded an indication of usage as you were talking about. There was only one little problem. We didn't know what the count meant or whether the thresholds for those counts had been properly selected. We didn't know if 590 degrees was when it should start counting or if 440 degrees or 600 degrees was better. The counts from the HSA would have accomplished what you were talking about if we had been smart enough to know what those counts meant when we got them and where we should start counting.

MR. DOUBLEDAY. Yes, knowing what to do with the data has been the problem all along as near as I have seen it on the usage program that we have tried to do. The contractors come up with their theoretical structure curves say, on the turbine blades, and they will plot their curve and say, this is it. This is the law that governs. We've had the same situation. The F402, the Rolls Royce engine that is in the Harrier has a hot section counter on it since day one. Only after years of experience are we now having little confidence in the fact that those numbers will have usable correlation with the damage that we are seeing. But in the beginning, the contractor would say, "oh well, you have got 300 counts, you have got to pull the engine." We would pull it and it would look fine.

MR. GARNER. Some agreement must be had on a definition of cycle in our industry so we can use these type systems. Some of us are going to suffer from the establishment of this standard and yet some of us are going to get a more optimum operation and some of us are going to be the other way. The standard will give us something to gear off of, some take-off point.

COL VAN HORN: Why do we need a standard cycle? You say we are going to need one; I disagree. I have to agree that I think each individual mission requires a different definition of a cycle. What would we gain? Since we know what low cycle fatigue is, we have a good definition of that. Each manufacturer knows how low cycle fatigue affects the component in his engine, why do we need to define air industry wide standard?

MR. GARNER. Because each manufacturer tells us that you have got a certain limit to go by.

COL VAN HORN. And that information is what you put into your planning and that information is what goes into accelerated mission testing and every other place that you test that engine. Take the air-to-ground versus the air-to-air mission. In the air-to-air mission, you are in a completely different speed regime, a different altitude regime, and you are at a higher power setting for a longer length of time. In the air-to-ground mode, you take off, you level off, you cruise to the target and then you pull the power all the way to idle while you are attacking the target you repeat the attack numerous times. And then you go all the way to the max power/stop climb back out, come home, and then come all the way back to the idle stop and land. This usage is a completely different one from what you had in the air-to-air mission.

MR. GARNER. Which is the hardest on the engine?

COL VAN HORN. The air-to-ground because you have more high to low power excursions with more cooling down.

MR. DOUBLEDAY. My feeling on the standard cycle is just as I said before, if we try to come with a universal standard cycle I think we will essentially be in the same situation we we are now using hours as the engine condition indicator. The standard cycle will of necessity be an approximation of what is happening to the engine. What we want to do is get as accurate an indication of engine condition as we can safely use up the life in all those engine parts. We can't afford new ones to replace them. We have got to get as much use out of everyone as is safe. If I could have a serial number on every blade and could rank the usage available on each of them, I would like to. Let's have ATC's view.

ATC VIEW

BY

LT COL R. G. GILLIS

ATC/LGM

AV 487-2794

COL GILLIS - ATC

I HAVE HEARD OTHER PEOPLE TALK ALL DAY ABOUT ATC'S POSITION ON DIAGNOSTIC DEVICES. SO, I WOULD LIKE TO SET THE RECORD STRAIGHT ON WHAT ATC REALLY WANTS AS A DIAGNOSTIC TOOL. WE ARE NOT SAYING THAT WE DON'T WANT DIAGNOSTICS. WHAT WE ARE SAYING IS WHEN WE DID THE ENGINE HEALTH MONITOR (EHM) TESTS ON THE T-38 WEAPON SYSTEM, EHM WAS NOT COST EFFECTIVE. WE HAVE HAD 15 YEARS EXPERIENCE ON THE J-85. AND, TO SPEND THAT MUCH MONEY FOR THAT DIAGNOSTIC DEVICE WOULD NOT BE COST EFFECTIVE FOR US. THE EHM DID SOME GOOD THINGS BUT NOTHING THAT WE COULD NOT REALLY DO OURSELVES GIVEN OUR EXPERIENCE LEVEL WITH THE ENGINE. HOWEVER, WE ARE BUYING ANOTHER AIRPLANE TO REPLACE THE T-37 AND WE DEFINITELY ARE INTERESTED IN DIAGNOSTICS FOR THAT ENGINE.

IT IS VERY DIFFICULT TO SAY SPECIFICALLY WHAT WE WANT AS FAR AS DIAGNOSTICS ARE CONCERNED BECAUSE WE HAVEN'T DEFINED WHAT ENGINE IS GOING INTO WHAT AIRFRAME YET. BUT, IT HAS TO BE A SIMPLE ENGINE. REGARDLESS OF THE ENGINE THAT WE GET FOR THE T-37 REPLACEMENT, WE THINK THAT THERE ARE SOME THINGS THAT NEED TO BE CONSIDERED, FROM OUR VIEWPOINT, ON DIAGNOSTICS. ONE IS THAT WHEN WE ARE DEVELOPING THE ENGINE, WE OUGHT TO GIVE THOUGHT TO PUTTING THE PADS ON THE MACHINE FOR THE CONCEIVABLE PROBES, WHICH WE MAY NEED. LET'S DO IT WHILE WE ARE BUILDING THE ENGINE AS OPPOSED TO GOING BACK IN THERE, TEARING IT APART, PUTTING THE PROBES ON, AND SPENDING A LOT OF MONEY TO MODIFY

THE ENGINE LATER. LET'S GO AHEAD AND PUT THE PADS AND WHATEVER MOUNTING DEVICES ARE REQUIRED IN THE BASIC ENGINE SO THAT WE CAN LATER ADAPT ANY DIAGNOSTIC SYSTEM THAT WE ARE TALKING ABOUT NOW AS STATE OF THE ART WHEN WE DECIDE WHAT IT IS THAT WE WANT. WE FEEL THAT APPROACH WILL BE MUCH MORE COST EFFECTIVE.

THE ENGINE WE FORESEE FOR THE T-37 REPLACEMENT IS A SIMPLE NON-AFTERBURNING FAN. WE WON'T NEED THAT MUCH OF A DIAGNOSTIC SYSTEM. BASICALLY, WHAT WE ARE AFTER IS THE SIGNATURE DETERIORATION AND INCIPIENT FAILURE DETECTION APPROACH WHICH WE THINK WOULD BE BEST IN OUR ENVIRONMENT. WE WANT SOMETHING THAT HAS A CONTINUOUS MONITORING RECORDER THAT WE CAN RECOVER DATA FROM AND IS EASILY ACCESSIBLE AND AIRFRAME MOUNTED. ALSO, WE WANT EXTERNAL ACCESS TO EVERYTHING WE NEED TO SERVICE--EXTERNAL ACCESS WITHOUT DROPPING THE ENGINE TO REPLACE THE DIAGNOSTIC PROBES. AND, WE FEEL THAT IS WITHIN THE STATE OF THE ART AT THE PRESENT TIME.

I HAVE HEARD TALK TODAY ABOUT SIGNATURES AND TRACKING. WITH THE NUMBER OF ENGINES THAT WE WORK WITH PER BASE (WE HAVE PROBABLY 100-120 T-38s AND 80-90 T-37s PER UNIT TIMES 2 ENGINES APIECE), WE HAVE A LARGE TRACKING PROBLEM. TRYING TO KEEP TRACK OF EACH AND EVERY SIGNATURE IS A BIG PROJECT RIGHT NOW AND, AGAIN, IS NOT REALLY COST EFFECTIVE BECAUSE WE DON'T HAVE A PROBLEM. WE CAN SEE THAT IT WOULD BE BETTER IF WE COULD DO THIS, YOU KNOW, IT WOULD PROBABLY SAVE US MONEY. BUT, ESTABLISHING THE SYSTEM RIGHT NOW FOR OUR PRESENT ENGINES WOULD NOT BE PRUDENT. BUT, WE SEE THAT AS THE ANSWER TO BRINGING A NEW ENGINE ON-BOARD, IF WE CAN AUTOMATE THE PROCEDURE.

ATC IS NOT OPPOSED TO DIAGNOSTICS AS HAS BEEN BANTERED ABOUT HERE. WE DO LOOK FORWARD TO DIAGNOSTICS ON THE NEW AIRPLANE AND THE SIMPLER THE BETTER FROM OUR STANDPOINT. AND, AGAIN, WE REALLY THINK THAT IF IT IS DEVELOPED CONCURRENT WITH THE ENGINE DEVELOPMENT, THAT WE WILL DO EVERYONE A FAVOR, INCLUDING OUR FRIEND FROM OSD, AS FAR AS SAVING MONEY IS CONCERNED. I DON'T HAVE ANY OTHER COMMENTS ABOUT ATC'S POSITION ON DIAGNOSTICS BUT I WILL ENTERTAIN ANY QUESTIONS ABOUT OUR ROLE IN EHM. QUESTION: IT WAS SAID BY SOME PEOPLE, INCLUDING MYSELF, THAT HAVING DATA, HAVING A DEFECT, HELPED THE ENGINE MECHANIC UNDERSTAND HIS ENGINE QUICKER--SPEEDED UP HIS TRAINING PROCESS. I AM NOT SURE IF THAT IS A FUNCTION OF YOUR COMMAND OR NOT. IF IT IS, WOULD YOU LIKE TO ENSURE THAT YOU HAVE THAT CAPABILITY IN THE SYSTEM? ANSWER: CERTAINLY, THAT WAS A DEFINITE BENEFIT OF EHM AT RANDOLPH WHERE WE TESTED IT ON THE 10 AIRPLANES WE HAD MODIFIED. BUT, AGAIN, WE HAVE A LOT OF OTHER WAYS TO TRAIN AND WE COULD NOT JUSTIFY EHM ON THAT BASIS. WE HAVE A LARGE CIVILIAN POPULATION IN OUR ENGINE SHOPS BECAUSE WE ARE A FIXED BASE OPERATOR AND HAVE NO MOBILITY COMMITMENT. WE CAN MAINTAIN STABILITY. CERTAINLY, A NEW GUY COULD LOOK AT THE EHM DATA AND SAY, "YES, I UNDERSTAND THAT BETTER NOW." DEFINITELY, THAT WOULD HELP. BUT, WE COULDN'T JUSTIFY BUYING THE SYSTEM ON THAT ALONE. YES, IT IS A DEFINITE SIDE BENEFIT. THANK YOU.

THE SAC VIEW

COLONEL JAMES K. STREETT, HQ SAC/LGME

I am going to give you a little change of pace to get across a little philosophy from an equipment user and maintainer to those of you here in the equipment development business. I am going to tell you a parable which embodies some of that philosophy. I think if you will listen close you will recognize the message I am trying to get across.

The parable goes: Once upon a time long ago in the land of the Turks lived a camel driver named Hanrihand. Hanrihand owned a camel taxi service and he had a camel named Hibuju. Hibuju was a fine camel, a good speciman, with long legs and great speed. He was indeed the fastest camel in the East. In addition to being speedy he could also go very long distances without refueling, because he had two great humps on his back that would hold humongeous quantities of water. So he had a good unrefueled range. He was also very healthy, very seldom showed up sick. His availability rate, then was very high - 99.7%. But this very fine camel had one serious drawback which bothered Hanrihand, his owner, no end. As I mentioned, Hanrihand was in the taxi business and Hibuju was his taxi camel. With his speed and his range and his high availability, he had good potential to make a lot of money. But unfortunately, people being what they are and camels being what they are, Hibuju was a very proud camel. He knew that he was fast. He thought he was racing quality. He didn't just want to be a taxi. He would rather race in the Turkish Camel Derby and have the pretty girl put the flowers around his neck when he came in in the money and that kind of thing.

So he was very uncooperative in the taxi mission. Many times he just refused to kneel down when Hanrihand wanted to stop and pick up a fare. And if the camel wouldn't kneel down the people can't get up on the camel. If you have ever riden a camel, you will appreciate that fact. And if the passengers couldn't get on because Hibuju wouldn't kneel down, Hanrihand wasn't making very many kopecks. He had a problem. So Hanrihand went to the camel equipment developers to see if they would come up with a solution to his problem. He wanted to find some way to make Hibuju cooperate and increase his profitability. Well, the first firm he went to was the firm of Watt and Plitney. He presented the problem and they said, Sure, we can solve it. We can build some camel loading equipment that will take care of it. So they took three years and they developed a piece of support equipment. It was called an Automtatic Axial Driven People Loader. The acronym was AADPL. This piece of support equipment was towed around behind Hibuju. It had a long arm with a bucket on the end, a kind of a scoop. It was powered by the wheels while being towed. When they would get to where there was a fare to pick up, Hanrihand would push a button and the scoop would go out, pick up the people and the arm would swing over and place them up on Hibuju's hump. But there were a few problems, in that there were a lot of injuries to the passengers and Whit and Platney had to take another three years to work out the safety aspects. The OR rate wasn't too terrific because this was a wonderful gadget of cogs and bearings and ratchets and pinions and pawls, all of which needed frequent adjustment and calibration. So Hanrihand found that he had to hire a crew of adjusters and calibrators. And he bought many volumes of technical orders from Fleet and Whutney and he hired these adjusters and calibrators and gave them the technical orders. But these first term adjusters and calibrators couldn't read the technical orders. They were written in Greek because Pleett and Whatney had hired a Greek to write them, naturally. And they couldn't understand it very well. So the first term adjusters took out their stone hammers and they did their adjusting and calibrating as best they could, by guess and by golly, which didn't turn out to be quite good enough. So Hanrihand found it was costing him more in maintenance and bad customer relations than he was making in fares from the AADPL so he gave up and turned it into R&M. Then he went to the next devloper, Generous Electric and they said, Sure they could solve the problem. They said that if Hibuju won't kneel down we will just bring the customer up to his level and he won't have to kneel down. We will get the people to load from an elevated platform. And they proposed to build a series of elevated platforms all over the country, at every trail intersection. That would be a good solution. No hassle for the customers, nothing to injure them, nothing mechanical to go wrong, no maintenance on the platforms because they would all be built solidly out of stone. The only drawback was that when Hanrihand got out his RFP for the system of platforms, the low bid came in for 27 drillion crocknicks and Hanrihand didn't have that much folding green. And the banks would not loan anything over 10 zillion drachmachs. His Master Charge card was extended to his credit limit, so he was back to ground zero. Well, he was sitting in the sand on the corner bemoaning his fate and trying to get Hibuju to kneel down and along came a feather merchant traveling up from Ephesus with an old flea bitten camel carrying a load of firewood. He was taking it up North to sell to the Turks in the desert where they didn't grow any trees. But the feather merchant stopped when he saw Hanrihand looking so dejected and asked him the problem. And Hanrihand told him the story about how he had a good money making proposition but he just couldn't get it to work because Hibuju just wouldn't kneel down. So the feather merchant said, "I have been driving camels for lo these many years and I know the solution to your problem. It's simple. You take one of these pieces of firewood and you give him a good swift rap in the back of the knees and he is going to kneel down. If he doesn't, you rap him again." So Hanrihand took the stick of firewood, about three inches in diameter, hauled off and swatted him on the back of the knees and sure enough, Hibuju didn't take much to that and he kneeled down so he wouldn't get swatted again. Well, the problem was solved and that is the end of the parable.

I said I was going to include a little philosphy in there and I think you probably picked most of it up. First, from the user point of view, I urge the developers to keep the solution on the same scale as the problem. Too many times we try to take such a quantum leap in technology that the solution gets out of hand with the problem, gets far ahead of it, and solves problems that weren't even there to start with. I spent about a quarter of my career in Systems Command and I have seen programs start with reasonable objectives, add on requirements that are nice to have, get too ambitious, and get hopelessly hung up in the development cycle, engineering the thing to death but never getting a workable product out on the street. I don't mean to say that is the general run; I mean to say we can fall into that trap if we are not careful. We can bite off more than we can chew, run out of time and money, and end up with a cancelled program, a few years of work, but nothing that really helps the end user. So I urge us all, when we design our development programs, to design them with reasonable objectives, and stick to the objectives. Or if you change them, have a better reason than "it's something nice to have" or that your vendor says - "this would be a really good deal". We need to select bite-size chunks in development that we can achieve in a reasonable time, engineer them, get them out into the field, try them out, see how they work, and then put some of it, at least, into operational use, as Andy is about to do with ICEMS. Get the feedback from the field use before you go on with the next stage of your development. If we don't, we end up building an elephant that can never learn to stand up on its own feet and we have to keep supporting it forever, when it should be carrying us. We have seen those kind of programs, I know. Keep your objective clearly in focus.

Another point I want to make is kind of a follow -on the last point. We get the little-boy-in-the-candy-store syndrome, we want everything we see. We, the users, go overboard in defining requirements and you, the developer, go overboard in meeting those requirements. We do get overambitious when we define our requirements. So you should make us thoroughly scrub down our requirements and make sure they are reasonable and that they are real requirements. As I say, the boy in the candy store looks around and everything looks good, and he says, "I want some of all of it." But he doesn't know that it is not all good for him. If we go for more than we need, we are going to suffer in many ways. We might make our project more capable, our system more sophisticated, but we might lose reliability. We might lose time when time is of the essence, when we should be getting the product out on the street now. We may make it more complex and, in turn, more capable but, indeed, harder to maintain and lower its availabiltiy. These are all trade-offs. Industry fosters this more-is-better and bigger-is-better approach. The salesmen come in with wonderful visions, make them sound like proven technology when it is really only an idea in somebody's head and we fall for it because we want to believe it. We want to believe their engineers can do all the things their salesmen say they can do. So we tend to generate requirements around sales pitches and go into long development perfecting something we never had a real need for, spending our money and our energies in the wrong place.

We need to keep our costs and our benefits in perspective. I know you have been hit with life-cycle cost concepts pretty hard lately. It is kind of hard to define life-cycle costs when you come right down to it. But we need to look at it; we need to keep them in perspective. There is no future in spending a million dollars on a project that only has a potential payoff of $100,000 a year, say, when it hits the street. That doesn't make fiscal sense. There's lots of areas in the logistics side of the house where there is ample opportunity to make a lot of money with some good well-spent development dollars. When we go down our logistics support costs ranking list that comes out the Depot, for SAC airplanes propulsion always heads the list and I presume that's the same for the other operational commands. There is lots of money to make improving engine reliability and maintainability. We invite your cooperation in defining the right areas and attacking the right problems.

Another point that I want to make is to keep the user and the maintainer and his environment in mind when designing equipment or modifications. It does a world of good to get development engineers out to the operational bases to visit, to tramp the flightline in the winter time, to walk into the shops and talk to the people bending the wrenches. I came from the development world into the maintenance world and I got a lot of surprises. We have to realize that the majority of our maintenance people are not experienced NCO's like Ray Straus or Ken Pobanz. The majority of the people down there in the shops and on the flightline bending wrenches are first term airmen. They are bright enough but they are very young and they are very short on experience. They don't speak in engineering terms so our tech data has to be written on their level. If you give them half a chance, give them a job to do, and define it well, they can do it well. But we have to communicate with them in their language, starting from where they are, not from where we are or where we think they should be. We have to keep them in mind when we are setting up our procedures, our equipment, and our tech data. Next point, when we are designing test equipment or support equipment to go along with our primary product, we not only have to be sure that we make the equipment do its job, but it has to be reasonably easy to use. I have gotten some surprises in SAC when I go and visit bases and find lots of wonderful equipment that has been bought and paid for that sits on the shelf because it is more trouble to hook up and use than it is worth once they get it hooked up. We have to keep that in mind. We have flightline equipment that is too big, or too bulky, or too delicate to be towed out there behind a tug. So we must keep the environment in mind when we are designing our support equipment.

Finally, I want to echo what Walt said this morning about limiting our data. Don't smother us with printouts that we don't need. I am not speaking of the development cycle; you need all sorts of data when you are engineering and testing. But when you put it out into the field as a qualified product, if you inundate the technician with data printouts, they sit in the corner or go in the trash can. We tend to overstate the data requirement, I think, quite a bit. And as an example of that, several years ago I stopped in Oklahoma City and I looked at the product that the C-5 wing at Dover was sending down to OK City out of the MADAR system. They were swamped with data at OK City. They bought a new processor so they could process it. They still had more than they knew what to do with and they had to put inhibits at the source on most of the data that was programmed to come out. They ended up trending only one engine parameter - TIT margin - out of all the data they had, which meant that OK City was using perhaps 1% of the data that was

Designed to be used by the MADAR's developers. So keep that in mind, too, when you are planning data requirements. As I said before, I am an engineer from the development community who moved over into a using command. It was very enlightening to get into maintenance. I joined the SAC staff about seven years ago in a troubleshooting role in aircraft maintenance engineering and it has been very fast paced and exciting. There have been a lot of alligators here in the swamps to fight off while we are waiting for you engineers to drain the swamp. So my message, I guess, is just keep working to drain the swamp and once in a while give us a hand on the alligators that are there chewing on us right now. Lets keep talking together so we can pass the lessons learned back to you, so you can make sure in the next swamp that the same alligator that we killed once doesn't get resurrected to come back and bite us again. That is about the end of my philosophy. I am still open to questions if there are any.

NAVAIR/NARF VIEW

BY

MR. GERALD SCHULTHEIS

NARF NORTH ISLAND

AV 941-6623

THE NAVAIR/NARF VIEW

MR. GERALD SCHULTHEIS

I have been here in Tullahoma about three days now and I have seen my home town of San Diego twice on TV, something I didn't expect. One was the Charger-Cowboy game and the other was the winners of the "Dating Game" got to go to San Diego. Both times, there was a lot of scenery I enjoyed seeing.

You've all heard of the Navy's Reliability Centered Maintenance (RCM) engine program. One of the things that we are trying to do is to come up with the most effective maintenance at the lowest cost while still maintaining fleet operational readiness. That sounds like a lot of "apple pie and motherhood," but really it's the name of the game in DOD. Someone said tonight that they were tyring to show cost savings--more importantly, show savings in man-hours and manpower. To the contrary, I think Colonel Van Horn pointed out very nicely, "Don't show savings in manpower and dollars, show savings in down-time and increases in operational readiness because those are the things that really sell." When you show other savings, "the powers to be" take money away from you and reduce your number of people. Lord knows, we all have more of a task to do than we really have people for. And, when they take people away from us in these times of scarce resources and competing requirements, they make an already bad situation even worse. What we are trying to do in the Navy's engine program, which is, as I said, a part of Reliability Centered Maintenance, is to find out the best ways to maintain our engines at the cheapest cost and with minimum down time.

In terms of engine health monitoring, we have chip detectors, oil analysis, and some black boxes in the A-7 and F-18 aircraft. But we have done a couple of other innovative things, and I say that in quotes. We've removed engine MOT because, as the studies have shown, our repaired engines went to about 250 hours and our overhauled engines also went to about 250 hours before removal. NAVAIR got hold of a study that was done by GAO that said, "Why overhaul the engine if you get the same kind of reliability out of an overhauled or repaired engine; repair them all." Our concept of overhaul, at that time, had been the IRAN concept; i.e., Inspect and Repair As Necessary. The Air Force smashes their engines when they come in the door and completely rebuilds them and "zero times" them. Both concepts have their good points, the benefits and pitfalls of which I will leave for discussion later.

How does all this relate to engine health monitoring? It is much more important on the newer generation of engines than on the older ones. Take the T58 and the J79 which I am responsible for. These are engines that have matured in the field and we know a lot of their problems (the bad actors). We know that we have gearbox problems, hot section problems, and low-cycle fatigue problems to mention a few. And we try to be as smart as we can about all these different problem areas we know about. Now on a new engine like the F404 that we are very concerned about, we don't know the "bad actors" yet because it's a new engine that hasn't been in the field. Reliability Centered Maintenance and performance monitoring are vital to the success of a new engine. The F404 is also a modular engine, a concept that we have never handled in the Navy. We have tried to address our older engines like the J79 and treat it as a modular engine but we have never had experience with an engine originally designed with that concept in mind. We have gone to the Air Force and have tried to learn the lessons you have learned on your F100 engine. And there were some lessons learned there. Some being: Make sure you have tech data in place before you put the engine in the field; make sure your training is appropriate and timely: make sure that your specifications for components are tight enough so that when you have component buildup, your overall specifications for the engine are still adequate. To mention a few, we are trying to learn these lessons and apply them to our new F404 engine program. The subject of low-cycle fatigue was brought up several times. One of the problems associated with modular engines is the incorporation of time compliance tech directives which were usually incorporated at the depot. In the modular concept, only components, not the engine itself, come back to the depot. At the depot, the tired metal (low-cycle fatigue) could be replaced as a normal course of action without aircraft grounding. Again, many of the things that we do with the older engines are going to apply to the newer engines, and we have to be smart about our methods.

In terms of engine health monitoring, I personally feel, and I am sure that everybody here thinks that this is a good idea. I've heard voiced different point of view such as: "a need for a lot of data" and "a trend for monitoring a lot of engine parameters." And, on the other hand, "We don't need to be inundated with data, what we need is critical data"; both ends of the spectrum. We all agree that engine health monitoring is important, but the way we go about it is one of the reasons we are here. You can't have your cake and eat it too;that's life! What we are going to have to do is decide what we need and then use our neads satisfying those needs,

This is my first Tri-Service Diagnostics meeting and I've been favorably impressed with what I've seen and heard. Since we all agree that engine health monitoring is needed, then I guess I would say that the "road blocks are what you see when you take your eyes off the goal." So let's pursue efficient and effective engine performance monitoring and get on with the business. And with that, I'll close and entertain questions about the Navy's engine programs. Thank you.

MAC VIEW

BY

COLONEL LOWRY

MAC/LGM

THE MAC VIEW
COLONEL LOWRY, HQ MAC/LGM

W. C. Fields once said that, "I spent a year in Philadelphia one night." Col Van Horn said, "I spent two years in Tullahoma one night." My wife and I drove down to Lynchburg and went through the Jack Daniels Distillery and I learned three things about diagnostics and monitoring down there. First of all, you have got to have the right kind of water. You have got to have the right kind of grain, and you have got to put that stuff down through the charcoal. And what you get is what you call Tennessee Jack Daniels. And they monitor that very closely. They won't give you a drink down there; it's a dry county.

I am out of the Hq MAC/LGM or Logistics Maintenance Shop. Primarily I have always been an operator; I am not an engineer. I always wanted to be one but then I couldn't do the other things I wanted in life so I chose to go the other way. Spent a lot of time in airplanes. Interested in maintenance. Got into maintenance kind of late in the game. In the field maintenance business, you get promoted and end up traveling around in IG jobs and all of a sudden you are the maintenance authority making decisions based on your viewpoint as an experienced operator supposedly with some technical expertise.

You can always go out to the real experts, the troops in the field and ask how does it really work? Master Sergeant Starrett who is really our Hq MAC expert in the business was to talk to you about some of our diagnostics and monitoring systems. However, his son, a twenty year old boy, had open heart surgery at the Mayo Clinic about three weeks ago. He recovered very nicely. Last week, he came up with a gall bladder problem which required gall bladder removal Monday. So he is the bionic boy, as we call him now. Master Sergeant Starrett, MAC's diagnostic expert, could not make it to Tullahoma this time.

Speaking of cycles, you know it is very normal in MAC for a C-5 to takeoff from Tinker with a load going overseas. For the C-5, that flight is only one cycle on each of the four engines. It has two in-flight refuelings from our brothers in SAC before landing at Teheran. The takeoff and landing is what we call a cycle on the TF39 engine.

We are overcoming the pilot shortage with the long mission. We just won't let them land, then they can't go out and work for the airlines. But we are really getting into the long mission business. But what I am saying is that we and probably SAC in their B-52s and their 135s have long hours between takeoffs and landings. I just came back from Mildenhall, Saturday, in a C-141 with a nine hour flight plan. In the MAC flight profile we have a lot of time for manual monitoring. A fighter pilot has his hands full going up and down and coming around and therefore has little time to record engine data. In MAC, we have flight engineers, pilots, navigators, and all sorts of people available with time on their hands.

So we are into monitoring. We have, of course, some fine engines. MAC flies the C-5 with the TF39; the C-141 with the TF33; the 130 with the T56, the T-39s with the J-60; C-9s with JT8s, commercial type engines, and helicopters. We watch all these type engines but we don't watch any of them as closely as we watch the TF39 and the TF33.

MAC has two types of monitoring systems in use. We have the MADAR system on the C-5 and an adaptation of the SAC ECMP for the C-141. MADARs is of course a real fancy name for Malfunction Analysis Detection and Recording system. That is our black box approach which has a little CRT unit and a nice little paper readout for the flight engineer. He can punch a bunch of buttons and he reads about twenty seven engine parameters on the TF39. It does all sorts of fancy things rather than just reading EGT or N_1 and N_2 and fuel flow. MADARs records twenty seven parameters, and feeds them into a computer center at Dover or Travis. The data is then pumped into Oklahoma City. Like Colonel Streett says, Oklahoma City ALC has all this data and, now, does little with it. Well, we are correcting a lot of those problems and we are currently using the data to identify trends in EGT margin for our TF39 engines.

For the TF33 we don't have that automated data capability. Since 1 Oct 1978 we have the MAC C-141 flight crews manually record in flight engine data. We say, "everybody reads the instruments now, more or less," and the data is recorded on a sheet of paper. We have just recently assigned one of our propulsion shop people the job of being an engine performance evaluation specialist. All he does is get these pieces of paper from the flight crews, correct the data based on the normal gas generator curves, and trend the engine's performance. This trend data has proven to be very effective.

Based on the success of the C-141 program, the TF33 engine has been taken off the 10,000 hour "tear the engine apart, zero time it, and put it back together" syndrome. We are going "on condition" flying the TF33 to max operating time and fix it when it fails. Certain "cyclic limited" items will continue to be changed on usage. The TF33s can be flown to max operating time with repairs made in an on condition mode because of our success with engine monitoring/diagnostics.

MADARs gets a lot of vibration readings in air that we can't duplicate on the ground. The problem is probably due to our ground test equipment being different from what we have for our MADARs in-flight vibration monitoring. MADARs uses velocity indicators opposed to accelerometers for ground test. This difference in methods has to be resolved if we are to make maximum use of MADARs vibration data.

Overall, we are pretty happy with the reliability of our engines. We have some problems, though. MAC is a command run by non-engineers. It is run by operators. I think Col Streett alluded to that. The engineers just don't run this railroad. It is run by the conductor in the back. Maybe that is not the way to run the railroad but that is the way MAC does it.

We have seventy-seven C-5s in our inventory. We have a few in our aircrew training unit at Altus and we have two operational C-5 wings, one at Dover AFB, Delaware, and one at Travis AFB, California. The very sophisticated MADAR system is on the C-5 aircraft. Those two C-5 wings in the calendar year have flown, I think, within 150 hours of each other. They each have the same number of aircraft and equivalent missions, yet one wing has a dramatically higher engine shut down rate than the other. Two years ago their roles were reversed. This year, Dover is having a dramatically high number of engine shut downs. Why is Dover having so many engines shut down while so comparable few at Travis. If I had the answer for the General, who is a four star, I could probably rise in the world, but I can't know for sure how to get that answer. We've got MADARs, which feeds the data to Oklahoma City, why don't we use that data to figure out why it is happening.

We have had a mysterious pylon fuel leak problem at Dover which we don't have at Travis. Crews are shutting down #2 engines because they are seeing what appears to be fuel vapor trailing off the pylon. The air oil breather is on the right side of all the engines. Normally, you can't see any of these breather's vents except on the #2 engine. You can't see the number one because it is too far out and you can't see the number 3 and 4 because they are on the right side of the engine. Have we got pilots seeing that one on the #2 engine and thinking it is a fuel leak? We think so and that is why we think a lot of our problems are in the human element. Problems from the human element apparently are rising significantly. And why are they rising? We think because of inexperienced people. At Dover we think part of our vapor problem (I don't think I am talking out of school) can be pinned down to about two crew members. They are keeping track of these two guys and have sent a guy out to fly with them. We have had a lot of engine shut downs because of one crew member saying, "I am seeing vapor from the #2 engine." And they are very sensitive to that because we had a #3 engine blow at Travis a little over a year ago with a fire, etc., in the pylon, which makes the story more interesting.

When I got into the MATS system years ago all the flight engineers appeared to be at least 50 years old with PhDs. They knew aerodynamics, they were very educated and could tell you when anything was wrong with the engine. What we now have in our cockpits is very different. Instead of the literally 45 year old captains, former airline pilots, recalled through a couple of wars - highly experienced people, we are now talking about aircraft commanders with 1500 hours, flight engineers with three to four stripes on their arms fresh out of maintenance. This is very limited time and experience for the complex aircraft we are flying.

If you talk about diagnostics and monitoring, the inexperience adds to an already difficult situation. I don't know how or what you design when you recognize the experience level of the people. You have to think about the real world human element. Our human element is better educated and bright but the experience level is way down and cannot rely on experience to bring them safely through the unexpected.

And as a result of lower experience level, you are going to have problems like the shut downs for breather vent vapors. Also there will be real fuel leaks generated , you could say maybe, bad maintenance or sloppy maintenance. Maybe it is poor inspection but we are short supervisors and we are short some of the quality things that we used to have years ago that we don't have anymore. I don't know yow you build a compensation into the system. Inexperience is what we are looking at now as the primary cause. That is our biggest problem. And we are looking at it as a major cause of problems in the TF39.

In the "Big War" scenario sort of thing, we would have to deliver our load with very minimal support and turn that aircraft around and come home. Reliable engines are a must. But it gets back to the quality of the human element. I just don't know how to solve it. And that is what I am making my pitch for tonight - is a human element. We are happy with our overall engine reliability. We are using diagnostics. We believe in its capability, we have proven that it works and are going to use it to operate our TF33 engines without tearing them down at 10,000 hours. We are going to press on and let diagnostics tell us when the TF33 engine can no longer do its thing for us. Anybody have any questions?

COL VAN HORN: Yes sir. I have watched the MADAR system work. MADARS monitors quite a number of parameters, and probably monitors fuel pressure. My question to you is, if in fact it does monitoring fuel pressure, are your people not believing what the MADAR system is telling them?

COL LOWRY: Well, the MADARs fuel pressure measurement is located where it is not sensitive to a pylon fuel leak. The fuel leak is in the pylon before it gets to the engine. The sensor is not in a location where it can measure the pressure change related to the fuel leak problem. We are monitoring fuel pressure at the engine, not in the fuel system.

Just last week we had a very serious problem at Dover. We had an engine blow up on the C-5 launching out of Dover. It was the #1 engine, blew after the third compressor stage blew the aft engine off. They were in flight, just taking off at around 650,000# gross weight or something like that on their way to Ramstein. Had a huge fire on the left side of the aircraft. Came in and reovered, landed and nothing else happened to the aircraft. Incidentally, the pilot that blew the engine at Dover last week was the same pilot that had the fire a year ago at Travis. He had nothing to do with the cause of that one either, of course.

We had a vibration problem out at Travis two weeks ago. The crew noticed the vibration on the MADAR. They had a slight vibration. Three hours into the flight they had to cage it for severe vibration and they found a ball peen hammer or the residue of a ball peen hammer in one of the turbine stages. It gets back into the quality and I am not trying to put our dirty linen out. The aircraft had been worked on that day. We have a consolidated tool kit program there (and SAC has it and I don't know if TAC has it), anyway the guy came into the shop and they counted his tools and he was missing a ball peen hammer so they red axed the aircraft. They spent supposedly a couple of hours looking for the ball peen hammer and couldn't find it so they assumed that it was stolen.

The engine was run-up prior to the crew accepting the aircraft at no vibration. Took off and about an hour into the flight they noticed a slight vibration in the MADARs and then three hours into the flight they had to cage the engine. And they found the head of the ball peen hammer with the CTK number on it which is like having the gun smoking in the hand of a murderer. Supposedly the guy was working up on top of the cowling and he put his foot in one of the vents or doors and supposedly the hammer fell off and down into the area and that is how it got lodged in the engine. At least that is the story and it is probably a true story. How do you overcome the human errors? I don't know how you monitor those things. Why didn't the MADARs pick up the vibration earlier? Interesting. Are there any other questions? I am kind of rambling on here. It was a pleasure coming down here. Thank you.

LT COL PETTIGREW: The last man up looks like he has two things going for him, first his organization has the greatest need for monitoring and diagnostic systems, second, he is the world's greatest pilot. Col Van Horn, it is all yours.

INFORMAL TALKING PAPER

ADDRESS TO TRI-SERVICE AIRCRAFT ENGINE MONITORING AND DIAGNOSTIC MEETING
6 DEC 78

- - - New propulsion maintenance tools and management practices must be developed to increase operationally ready rates and system reliability.

    - - - Need monitoring and diagnostics to:

        - - - Reduce maintenance costs.

        - - - Reduce contract costs.

        - - - Improve readiness.

- - - MAC has two monitoring systems; one automated and one manual.

    - - - MADARS (Malfunction Analysis Detection and Recording System)

        - - - Monitors 9 LRU and 28 engine parameters with magnetic tape recording.

        - - - Data treated at central data bank with output products at engine shop.

        - - - Strengths:

            - - - Monitors major engine parameters.

            - - - Data is useable for trending and trouble-shooting.

        - - - Weaknesses:

            - - - Poor reliability, maintainability, and high support costs.

            - - - Lack of correlation between flight and ground reading.

    - - - C-141/TF33 Manual Health Monitoring

        - - - Data gathered by aircrew from cockpit instruments.

        - - - Manually plotted with human interpretation of trend plots.

        - - - Successful in MAC environment.

- - - Need to apply lesson learned to future systems.

  - - - Test sufficiently to insure reliability, maintainability and, above all, accuracy.

  - - - Aircraft and flight line test equipment must be compatible.

  - - - Flight indicators must be compatible with test cell instrumentation.

  - - - Systems must be simple and avoid today's trend toward elaborate, expensive hardware.

- - - The challenge is yours to come up with a system that meets the users' needs; accurate yet dependable, reliable, but simple, and it must provide sufficient data to allow maintenance to readily determine what actions are required.

ACTION OFFICE: HQ MAC/LGMWP/SMSgt Frashure/2914

AUTHENTICATION: [signature] DATE: 27 [illegible]

J. M. MARTIN [illegible], USAF
Director of Maintenance [illegible]

THE TAC VIEW

ENGINE MONITORING/DIAGNOSTIC NEEDS

COLONEL BOYD L. VAN HORN, HQ TAC/LGM

Why do we need engine monitoring and diagnostic systems?

As you all know, the concept of engine monitoring is not new. Over the years it has been applied to a number of different weapon systems, with varying degrees of success. During the same period, we have also continued to operate most weapon systems using conventional methods. That begs the question, why can't we support newer weapon systems in the same way we supported the older ones?

The answer, of course, is that the cost of doing business today and the constraints that have been applied, dictate that we achieve maximum efficiency in the operation, maintenance and logistic support of our new and older weapon systems. The principal factors driving this are: The complexity of newer engines, increasing costs and reductions in funding. The emphasis continues to be to find new ways to do more with less.

Perhaps the overriding reason for engine monitoring is the on-condition maintenance concept. As you know, the airlines have used OCM successfully for several years, and DOD has directed it for the F100 and TF34 engines. It is clear from discussion and correspondence we have received that not everyone has the same perception of what constitutes OCM. This is the Air Force definition as listed in AFR 66-14. The point here is that the definition is necessarily general in nature. The issue is how does this definition track with our maintenance procedures in the past, at present and in the future.

OCM is an evolutionary process progressing from conventional methods to full OCM in the future. Listed here are some of the elements of each concept. In the past, using conventional methods we disassembled engines to assure serviceability. The result was that we detected and fixed some problems, induced some others in the process and detected the remainder as inflight failures occurred. To some extent we have improved upon that today. We are now looking forward in terms of detecting some problems sufficiently early in the failure cycle to permit repair prior to total failure. In some instances we are able to accomplish this without disassembly of the engine. However, we have not progressed to the point where we can accurately ascertain engine health or preclude inflight failures. The present concept represents a mixture of OCM and conventional methods. The bottom line is that in order to implement OCM we must have a higher order of engine monitoring capability than we have today.

Briefly, let's consider the effect if we continue to operate under the present maintenance concept. This vu-graph depicts the ratio of engines in the TAF fleet supported by conventional and OCM concepts today and in 1986. As you can see, by 1986 the majority of our engines will be under OCM. In order to support these, we must progress beyond the present mixture of conventional and OCM methods toward a purer form of OCM. To accomplish this we must develop that higher order of engine monitoring capability discussed earlier.

There are inherent advantages and disadvantages to both manual and automated systems. Commercial airlines and SAC have both had success with the manual system. However, we believe the automated systems offer more capability and are better suited to fighter aircraft engines. Particularly, single crew aircraft with an active mission. Although there are periods of time during each flight when recording of data by the pilot is possible, our experience shows that during most of the mission, the pilot's attention is focused outside the cockpit and many malfunctions go undetected until they develop into more serious problems.

In terms of basic system requirements, the functions listed here represent the basic requirements of an automated system. Most of these are within the bounds of current technology and are being evaluated on systems presently undergoing development service testing.

The following are some areas that require further effort. Gas path trending is an area of continuing difficulty. Our goal is to be able to accomplish this task at base level. Experience to date with the T-38 and A-10 programs has not been satisfactory. The systems are programmed to automatically record data during takeoff, climb and cruise when stability criteria are satisfied. We have experienced difficulty in generating usable data because of insufficient stability or use of part power during takeoff and formation flight during climb and cruise. Additional work is needed to determine the stability time required to attain an acceptable level of thermal equilibrium for trending. The results of this will determine whether or not automatic recording is practical or if aircrews will be required to establish specific flight conditions for data acquisition.

In the area of diagnostic logic, considerable effort needs to be expended to develop logic for fault isolation of events detected through trending, inflight malfunctions and particularly module isolation. The logic developed for these events needs to go beyond just duplicating present T.O. diagrams. It should incorporate data from the additional parameters provided by the system to improve fault isolation accuracy. Regarding modular fault isolation, a gross indication of gas path degradation is not sufficient. You will recall in the definition of OCM it refers to "the extent of repair required to restore serviceability." In order to accomplish this we need to know what percent of the total degradation each module contributes. That data will dictate the extent of repair required.

In the area of vibration monitoring, we believe that significant savings in fuel and manhours are possible if the necessity for installation/removal of vibration pickups and ground run are eliminated. Efforts to accomplish air-borne vibration monitoring on the T-38, and to date, the A-10 have not been successful. Generally, the output data is not reliable. Engines flagged by the system for high vibration, prove to be satisfactory when operated on the test cell. The cockpit indicator is another potentially valuable function of an automated system. The seriousness of many events, if detected early enough, can be minimized by pilot action. For example, if the pilot retards power to avoid an overtemp condition the maintenance action is then reduced to correction of the cause rather than also having to correct the effect. In addition to overtemp, oil pressure problems and impending stall are candidates for cockpit warning. Either lights or voice warning could be used to alert the pilot to these conditions. However, because the pilot's attention is focused outside the cockpit much of the time, if lights are used, placement is critical.

Crash hardening the airborne recorder was explored for both the F-15 and A-10 systems. It was abandoned because of cost and weight. Because survival of engine/airframe monitoring data offers an extra dimension to accident investigation, the concept ought to be pursued. A possible approach may be to feed critical data to a separate crash recorder located in the tail of the aircraft.

And, finally, one of the most important areas needing resolution, the interface required to input recorded dat into the base level data system. This interface and programs to handle the data must be developed early enough to permit adequate debugging prior to arrival of a production monitoring system in the field.

In summary, we conclude that attainment of OCM requires greater engine monitoring capability than we have today. We need an automated system for fighter aircraft.

And finally, while we believe we know what the basic system capability needs to be, that capability is not yet fully developed.

WHY DO WE NEED ENGINE MONITORING AND DIAGNOSTIC SYSTEMS?

LG 1423

WHY MONITORING/DIAGNOSTIC SYSTEMS

- MAXIMUM OPERATIONS MAINTENANCE AND LOGISTIC SUPPORT EFFICIENCY
  - COMPLEXITY OF NEW ENGINES
  - OPERATIONS/MAINTENANCE/LOGISTICS SUPPORT COST
    - SPARE ENGINES
    - SPARE PARTS
    - FUEL
    - MANPOWER
  - REDUCED FUNDING

LG 1424

WHY MONITORING/DIAGNOSTIC SYSTEMS

- ON-CONDITION MAINTENANCE (OCM)
  - DIRECTED FOR F-100 AND TF34 ENGINES
- OCM - THE APPLICATION OF INSPECTION AND TESTING PROCEDURES AND TECHNIQUES WITHOUT REMOVAL OR DISASSEMBLY THAT ALLOWS THE CONDITION OF EQUIPMENT TO DICTATE THE NEED FOR MAINTENANCE OR THE EXTENT OF REPAIR REQUIRED TO RESTORE SERVICEABILITY

LG 1426

WHY MONITORING/DIAGNOSTIC SYSTEMS

PAST	PRESENT	FUTURE
CONVENTIONAL	CONVENTIONAL/OCM	OCM
HARD TIME	PRE/POST FLIGHT	PRE/POST FLIGHT
INSPECTIONS AND OVERHAUL	PILOT WRITE-UP	SOAP
PILOT WRITE-UP	SOAP	PARTS LIFE TRACKING
SOAP	BORESCOPE	ENGINE MONITORING AND TRENDING
	PARTS LIFE TRACKING	

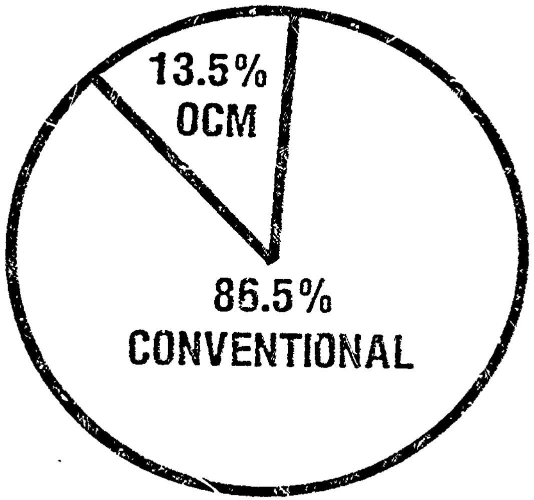
- PRESENT CONCEPT
  - COMBINATION OF CONVENTIONAL AND OCM
  - OCM REQUIRES A HIGHER ORDER OF ENGINE MONITORING THAN IS PRESENTLY IN USE TODAY

LG 1427

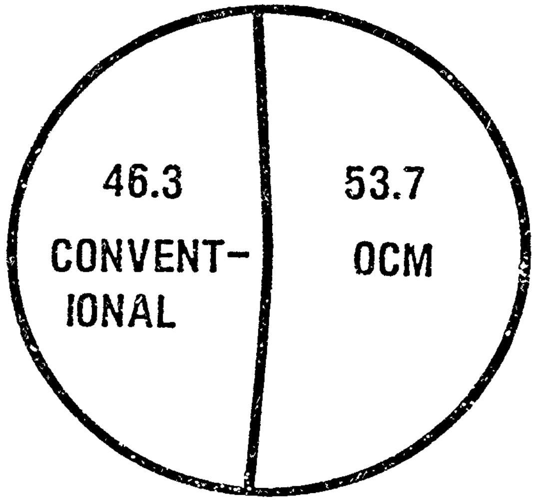
TURBO-ENGINE PIE

TAF (ACTIVE & RESERVE)

OCM vs CONVENTIONAL



1978



1986

LG 1428

WHAT TYPE SYSTEM IS NEEDED

- MANUAL vs AUTOMATED
  - BOTH HAVE ADVANTAGES/DISADVANTAGES
- MANUAL SYSTEM
  - BETTER SUITED TO MULTI-CREW AIRCRAFT WITH LONG PERIODS OF ENGINE STABILITY
- AUTOMATED SYSTEM
  - BETTER SUITED TO SINGLE CREW FIGHTER ENVIRONMENT

LG 1429

BASIC SYSTEM REQUIREMENTS

- AUTOMATICALLY RECORD
  - TIME AND CYCLE DATA
  - GAS PATH TRENDING DATA IN-FLIGHT
  - EVENT AND FAULT ISOLATION DATA
- PROVIDE GO/NO-GO STATUS INDICATION
- PERFORM IN-FLIGHT TRIM CHECK
- PROVIDE GROUND TRIM/REAL TIME READOUT
- FAULT ISOLATE TO LRU's/MODULES
- PROVIDE PILOT RECORD OPTION

LG 1430

PRESENT DEFICIENCIES

- GAS PATH TRENDING
  - INSUFFICIENT STABILITY
  - PART POWER TAKEOFF
  - FORMATION FLIGHT
- DIAGNOSTIC LOGIC
  - TREND EVENTS
  - INFLIGHT EVENTS
  - MODULE FAULT ISOLATION

LG 1431

PRESENT DEFICIENCIES

- VIBRATION MONITORING
  - POTENTIAL MANHOUR/FUEL SAVING
    - PRESENT SYSTEMS NOT RELIABLE
- COCKPIT INDICATOR
  - ALERT AIRCREW TO POTENTIALLY DANGEROUS SITUATION
    - OVERTEMP
    - OIL PRESSURE
    - IMPENDING STALL
  - INDICATOR LIGHTS OR VOICE WARNING

LG 1432

PRESENT DEFICIENCIES

- CRASH HARDENING
    - INPUT DATA TO CRASH RECORDER
- DATA INTERFACE WITH BASE LEVEL DATA SYSTEM
    - MUST BE DEVELOPED SOON

LG 1433

SUMMARY

- OCM REQUIRES ENGINE MONITORING
- FIGHTER AIRCRAFT NEED AUTOMATED SYSTEM
- BASIC SYSTEM NEEDS ARE DEFINED BUT

  NOT ALL HAVE BEEN MET

LG 1434

ADVANCED PROPULSION MONITORING SYSTEM

By: Mr. Keith R. HAMILTON

AFAPL/TBC, WPAFB OH

7th ANNUAL TRI-SERVICE DIAGNOSTIC MEETING

ARNOLD ENGINEER DEVELOPMENT CENTER

ARNOLD AIR FORCE STATION TN

7 DECEMBER 1978

ADVANCED PROPULSION MONITORING SYSTEM

INTRODUCTION

Increased complexity of aircraft propulsion systems become unavoidable with the requirements for higher performance and efficiency of modern aircraft weapons systems. In the past few years, these complexities coupled with large inflationary factors have brought about huge increases in aircraft engine acquisition, operational and support costs. In turn, these very high costs tend to limit the number of highly complex systems to be bought and requires keeping them in service longer.

To cope with these economic threats, the adoption of On-Condition Maintenance (OCM) concepts have become a very attractive alternative. Both a DOD Planning and Programming Guidance Memorandum (PPGM) and a USAF Program Guidance (PG-78-3), dated 7 May 1976, have been interpreted to require the performance of maintenance based upon the condition of the system rather than at specific predetermined intervals. Without the incorporation of adequate propulsion condition monitoring capabilities, the required observations of engine conditions may not be sufficient to take the proper maintenance actions and may result in extensive secondary damage or in the very costly and dangerous "fly-to-failure" operation alternative. For these reasons, a number of various turbine engine monitoring systems have been and are now being developed and tested for possible adaptations to in-service aircraft.

OBJECTIVE

The purpose of this effort is to design, develop and analyze new approaches that may be required to incorporate multi-parameter, aircraft propulsion monitoring system capabilities for future aircraft/engines through acquisition of the majority of their data signals to be converted as diagnostic information from other existing electronic subsystems. This research and development shall provide an engineering basis upon which designs of all propulsion-associated electronic subsystems for diagnostic purposes and the monitoring system, itself, can be considered early in the design and development of future aircraft weapons systems.

SCOPE

This program of work is expected to start in FY79 and be completed in 37 months, to develop, demonstrate and analyze the validity of the involved engineering design and operating functions devised. The work consists of four phases:

- Phase I - System Requirements Definition
- Phase II - Hardware Acquisition/Programming/Checkout
- Phase III - On-Engine Demonstration/Validation Tests
- Phase IV - Data Items, Documentations & Technical Reports

SUMMARY OF SYSTEM DESIGN

The APMS is required to demonstrate efficient methods of acquiring and storing of propulsion system diagnostic information obtained from other engine/aircraft electronic controls/subsystems in serial digital format. Since signals for engine/inlet controls, the air data computer and other aircraft electronic subsystems already exist, most of the instrumentation for the required sensing and signal conditioning already exists. The APMS shall provide data acquisition, in-flight self-tests, display, recording and ground transfer.

Requirements have been established for multiple data systems in MIL-STD-1553B, Aircraft Internal Time Division Command/Response Multiplexed Data Bus. As a design objective, the Advanced Propulsion Monitoring System (APMS) is to be designed to demonstrate compatibility and similarity with these techniques. These similarities are particularly important because of impacts on APMS modular design for increased reliability, reduced size, weight and data storage requirements. Modular units simplify operation usage practices and ease overall maintenance/replacement practices. Maximum usage of micro-processors and solid-state memory shall be made consistent with anticipated military aircraft mission profiles and on-condition maintenance concepts. Depending upon contractor system definition, a majority of the condition monitoring signals can be obtained from a full-authority digital electronic engine (FADEC), an engine inlet control and other aircraft electronic subsystems in serial digital format that is suitable for APMS diagnostic data acquisition and processing.

Additional condition monitoring signals are required for data not obtainable from other engine/aircraft electronic subsystems. These signals require separate signal conditioning and multiplex arrangements consistent with a digital data bus concept. The required design must determine the optimal mix of this concept consistent with overall program objectives. All inputs to the APMS processor and recording unit shall be provided in an acceptable format and acquisition control schedule consistent with APMS software routines. Additional sensors anticipated include: (See Figure 1)

- o Rotor and gearbox vibrations (e.g., unbalance, bearing problem, FOD impact)
- o Turbine interstage pressure and temperature
- o Turbine blade average/individual peak average temps
- o Lube oil debris accumulation rate and lube consumption

All APMS electronic elements designed as aircraft or engine installable equipments shall be consistent with MIL-E-5400R, and appendices thereto, for Category II equipments. For engine-mounted equipments, appropriate military specifications and limitations pertaining to or imposed by the specific engine shall apply. For APMS equipments that are to be primarily used in this effort as breadboard or commercially available, their usage shall not constitute a safety hazard.

A TYPICAL DEMONSTRATION CONFIGURATION

A typical demonstration configuration including some of the test equipment and data flow schematic are depicted in Figure 2. The developed APMS shall be required to demonstrate efficient methods of acquiring and storing of propulsion system diagnostic information with maximum compatibility and adaptability for eventual development as a production system version with similar objectives. The items marked with "A" are major hardware components of the engine/aircraft installed APMS and are to be provided as development models. The items marked "B" are primarily system programming, test and intercommunications equipment which may be provided as commercially available (slave) or breadboard in form. Other items of hardware such as support, test or utility equipment needed to program the system, provided simulation signals, functional calibrations and verifications may be utilitarian in form. All of the above hardwares or equipments are to conform to applicable safety standards for thier usage. The APMS validity and application feasibility is to be demonstrated on a contractor-provided test engine representative of current and future complex military aircraft turbine engines controlled by full-authority digital electronic engine controls.

The following descriptions of hardware/software are intended as a configuration design guide providing maximum representation of a flight type propulsion monitoring system, while at the same time, providing necessary R&D flexibility to program the APMS, make engineering software corrections, provide realistic simulations, etc. The full-authority digital electronic engine control development model (FADEC) provides sensor data in a serial digital format (e.g., FADEC model) updated approximately every 10 msec through identical field replaceable terminal modules. These modules contain the electronics necessary to plan, command and monitor the bus traffic. For the purpose of utility in this effort, only, bus control may optionally be accomplished by incorporating the control functions in the slave diagnostic computer or by any other representative arrangement. The APMS signal conditioner/multiplexer (SCM) is an on-engine mounted unit which accepts, converts and outputs signals from added sensors not available from FADEC (vibes, oil debris, turbine blade temp., etc., or those to be added because of unreasonable existing subsystem modifications). These signals are conditioned and formatted in the signal conditioner and then provided through the data bus to the APMS-Data Processing Unit (DPU). Aircraft signals that are normally obtained from other aircraft electronic subsystems are to be provided as input simulations through the data bus to the DPU. (e.g., Mach no., alt, ambient air press and temp, maneuver g-loadings, etc.).

The DPU must be capable of processing all the above-described condition monitoring signals every 1/4 sec or less. For every sample scanned, the individual parameters should be checked or tested in this processor aganist established limit levels of concern to eliminate erroneous signals prior to display or recording. A limited memory storage unit shall be incorporated capable of storing all data samples for a sufficient period of time prior to and after a DPU verified limit exceedence event. This temporarily stored data shall be successively discarded if no limit exceedence event condition has occurred. When the operating engine reaches any aforementioned limit, the processor is required to activate the recording of the data for post-flight ground analysis pruposes. The DPU shall provide input data through the data bus to the flight crew advisory panel (AP) which displays messages describing the reason for the events as may be needed for continued flight operational decisions or adjustments. An engine status panel (ESP) shall indicate next mission availability to flight-line maintenance personnel. All of these data and messages are to be stored in the Data Recording Unit (DRU) for post-flight in-depth diagnostic analysis to the module or LRU of concern. The DPU shall also cause selected blocks of data to be stored in the DRU at least once per flight for both the further in-depth diagnostic fault isolation and for trend analysis of engine deterioration in a ground central computer facility. These blocks of data shall be obtained during each aircraft take-off and also when any flight regime has become adequately stabilized for engine analysis purposes. These blocks are to be of sufficient length for analysis purposes and must be stored in an organized format such that "median" or "assumed true" values can be derived in the trend analysis processes. The DRU may be incorporated in the DPU module as a replaceable, non-volatie solid-state memory unit or for long range aircraft may be a magnetic tape recording unit depending upon the results of application design trade-off studies.

The Diagnostic Computer and Transfer Unit (DCTU) represents an optimal flight-line data retrieval, transfer and diagnostic unit. This unit is normally used on the flight line in case of fighter aircraft and as a portable/removable on-board diagnostic computer/recorder combination in case of bomber and cargo applications. This unit shall provide organized and computer diagnostic data as flight-line trim and troubleshooting information as well as trend/tracking/life usage data to be transferred to a ground central computer for further analysis. These data and information may be routed and controlled through an input/output (I/O) bus connecting the DCTU to a computer terminal/printer (CTP), the ESP previously discussed and Bulk Storage Recorder. The computer terminal/printer serves only as an R&D support means for engineering functional inquiries and read back, engineering tests, system checks, accomplishing programming changes and providing diagnostic hard-copy printouts of information and real-time advisories. This access is normally provided as a ground-based diagnostic system test and support equipment.

The Bulk Storage Recorder (BSR) is normally included as an element of the DCTU, but for purposes of test and demonstration flexibility, in this effort, it may be a separate recorder. The BSR must acquire and record all diagnostic data/records/information available from the APMS on a reel-type magnetic tape in a compatible format and suitable for off-line data reduction/printouts from a ground-based central computer facility.

A Central Computer Facility is to be used in the demonstration of APMS validity as an airborne integrated condition monitoring system and is representative of the computer facilities that would normally be available and utilized at a base maintenance shop (JEIM) and the large computer facility usually located at an AFLC Air Logistic Center (ALC). The computer facility for this effort must be programmed to accept and process the airborne recorded data and demonstrate that APMS data can be used for in-depth engine diagnosis; fault isolation and trend analysis computations; life consumed analysis of major rotating components and life-limited parts; provide parts history/identification records, permanent data recores and hard-copy diagnostic printouts.

END ITEM RESULTS

This research and development shall provide equipment design and data acquisition methods as the engineering basis upon which future aircraft weapons system design and development specifications can drastically reduce hardware additions and less effective retrofits needed to accurately and reliably monitor aircraft propulsion systems in support of timely decisions that can reduce maintenance costs, improve readiness rates and safety of flight. While it is not intended that the electronic hardware eventually intended for aircraft/engine-mounted installations, as shown in,Figure 2 of this SOW, be designed to preproduction standards, it is required that these specific equipments offer the least amount of redesign or further testing to achieve air-worthiness acceptance.

SUGGESTED APMS DATA SOURCES

ELECTRONIC ENGINE CONTROL

HEALTH CONDITION MESSAGE
INLET TEMPERATURE/PRESSURE*
ANTI-ICING BLEED FLOW (POSN)
POWER LEVER ANGLE POSN
FAN DISCH PRESS/TEMP
FAN PRESSURE RATIO
FAN ROTOR SPEED
COMPRESSOR VARIABLE STATOR POSN
COMPRESSOR PRESS/TEMP*
CORE ENGINE SPEED
CORE ENGINE FUEL FLOW
LOW LUBE PRESSURE*
LOW LUBE LEVEL
TURBINE INLET TEMPS
VARIABLE BYPASS INJECTOR POSN
AUGMENTOR LIGHT-OFF DETECTOR
AUGMENTOR SWITCH-ON
AUGMENTOR FUEL FLOW
EXHAUST NOZZLE POSN/THROAT AREA*

INLET GUIDE VANE CONTROL

HEALTH CONDITION MESSAGE
INLET GUIDE VANE POSN

AIRFRAME SUBSYSTEMS

HEALTH CONDITION MESSAGE (EA SUBSYS)
ALTITUDE**
AMBIENT PRESSURE
AIRCRAFT MACH NUMBER**
SQUAT SWITCH POSN (WOW)**
AIRCRAFT ANGLE OF ATTACK**
MASS FLOW BLEED MEAS**

SPECIAL C/M TRANSDUCERS (ADDED)

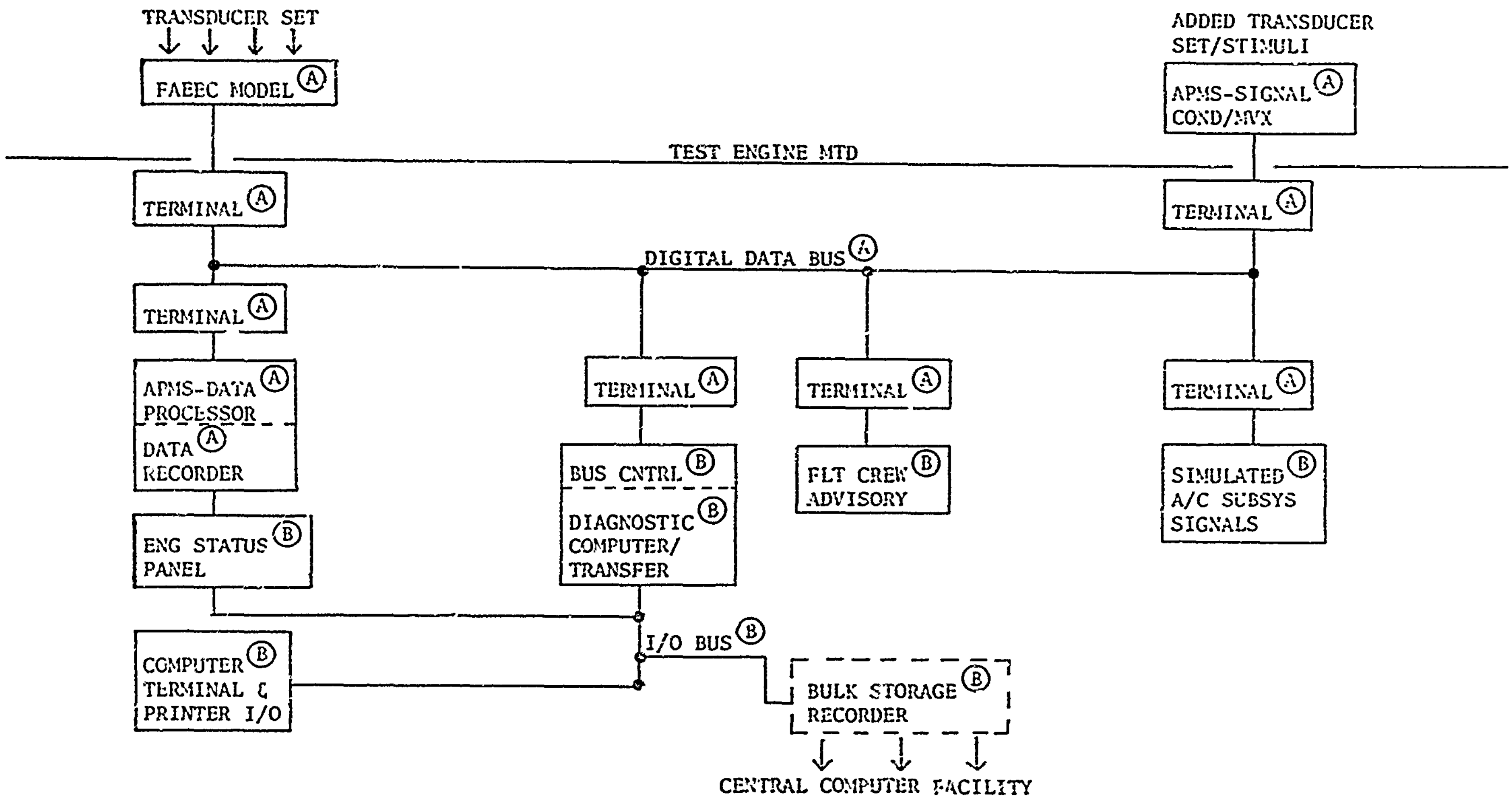
HEALTH CONDITION CHECK (DAU)
FAN ROTOR VIBS
GAS GENERATOR VIBS
GEAR BOX VIBS
TURBINE INTERSTAGE PRESSURE*
TURB BLADE AVG TEMP/INDIV PEAKS**
LUBE DEBRIS ACCUM/RATE**
AIRCREW OPTION SW (RECORD)
EMERGENCY ON/OFF SWITCH

* VARIATIONS IN EXISTING MODEL ELECTRONIC SUB-SYS MAY DIFFER AS DATA SOURCES

** MAY REQUIRE THROUGH-PUT STIMULI AS SIMULATIONS OF THESE DATA

FIGURE 1

TYPICAL APMS DEMONSTRATION CONFIGURATION*



*Configurations may vary because of differences in test engine selections & signals available from elec control/subsystem models.

FIGURE 2

THE GARRETT ENGINE MONITOR

US COAST GUARD APO

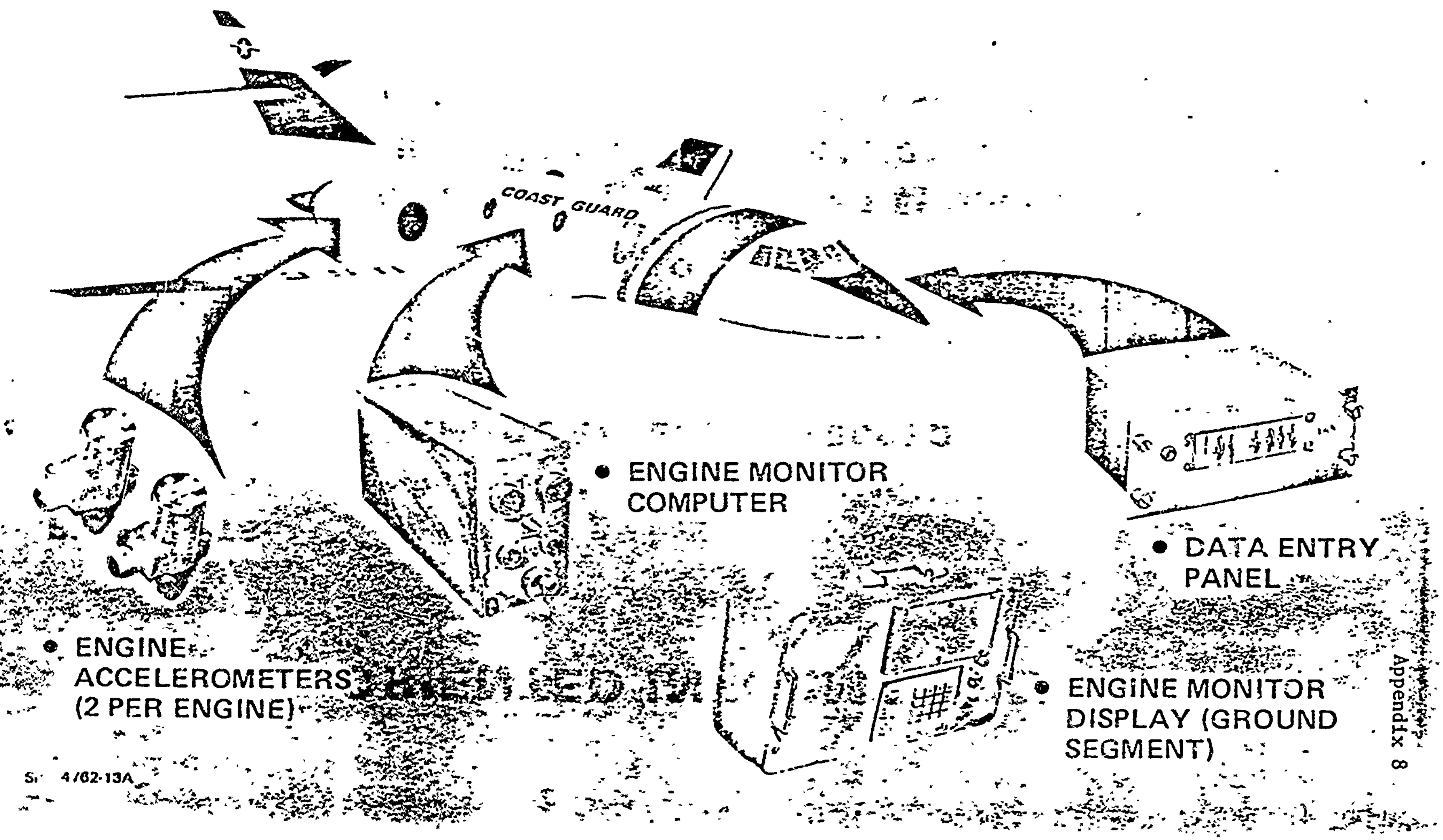
LITTLE ROCK ARK

ADI CHARLES C. CRIMINALE

HIGHLIGHTS

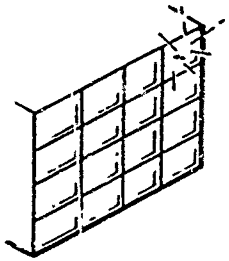
The USCG is acquiring the twin engine Falcon aircraft for their mission. These aircraft will have a Garrett EHMS system which uses the Digital Electronic Fuel control Sensor plus two accelerometers on each engine. The recorder collects and holds data from ten flights and will determine a severity of usage as a ratio to the standard mission profile.

THE GARRETT ENGINE MONITOR



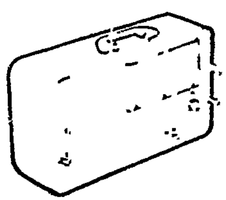
USER-ORIENTED INFORMATION

PILOT GETS:



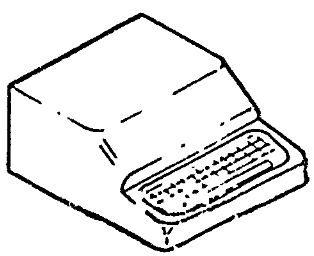
ALARM SIGNALS IN REAL TIME
AUTOMATIC EXCEPTION RECORD

MECHANIC GETS:



CONFIRMATION OF IN-FLIGHT ENGINE EXCEEDANCE
  TIME, PEAK VALUE, DURATION
MEASURE OF ENGINE DETERIORATION
  CHANGE/RATE FOR PERFORMANCE/VIBRATION
LOG DATA
  HOT SECTION LIFE, START CYCLES, HOURS

ENGINEERING GETS:



HARD COPY, DIRECT OR BY TELETYPE
  PRINTOUTS PERIODICALLY OR ON DEMAND

DATA SOURCES AND OUTPUTS

MONITOR DATA SOURCES
• ENGINE FUEL CONTROL COMPUTER
• ENGINE INDICATORS
• AIR DATA COMPUTER
• AIRFRAME CONTROL SWITCHES
• BLEED FLOW SENSOR SWITCHES
• ENGINE MOUNTED ACCELEROMETERS
• DATA ENTRY PANEL

MONITOR DATA OUTPUTS
• COCKPIT ALARMS
• FLIGHT DATA RECORDER (ARINC 573)
• ENGINE MONITOR DISPLAY (POST-FLIGHT)

SPA4752 11A

MONITOR FUNCTION: CONTROL TROUBLESHOOTING

FAULT CONDITION	PARAMETERS USED
• MONOPOLES	CONTROL MONOPOLES
• IGV ACTUATOR • IGV SENSOR	IGV POSITION, ACTUATOR CURRENT CONTROL N2, T2
• FUEL DELIVERY SYSTEM	TORQUEMOTOR CURRENTS (FOR OPEN) INDICATOR WF, CONTROL WF/P6, P2, N1, T2 (COMPUTED P6)
• T2 SENSOR	CONTROL T2
• PMG	PMG VOLTAGE, POWER VOLTAGE
• MANUAL MODE	CONTROL LOGIC

SFA 4762-9A

MONITOR FUNCTION: LIFE LIMITS

MEASURE	PARAMETERS USED
• OPERATING HOURS	MONITOR COMPUTER CLOCK, IGNITION, CONTROL ITT, N3
• ENGINE START CYCLES	IGNITION, CONTROL ITT
• TURBINE CREEP LIFE, EQUIVALENT HOURS	MONITOR COMPUTER CLOCK, CONTROL ITT, N3, INDICATOR ITT, N3 (MANUAL MODE)
• CUMULATIVE OVERTEMP TIME	CLOCK, CONTROL ITT, INDICATOR ITT (MANUAL MODE)
• CUMULATIVE OVERSPEED TIME	CLOCK, CONTROL N3, INDICATOR N3 (MONOPOLE FAULT) CLOCK, CONTROL N2 CLOCK, CONTROL N1

SPA 476? ?A

MONITOR FUNCTION: ALARMS

ALARM	PARAMETERS USED
• ROTOR OVERSPEED, N1, N2, N3	CONTROL MONOPOLES (ISOLATED) INDICATOR N3 (CONTROL MONOPOLE FAULT)
• INTERSTAGE TURBINE OVERTEMP	CONTROL ITT SIGNAL INDICATOR ITT (MANUAL MODE)
• START FAULT	CONTROL MONOPOLES (ISOLATED) CONTROL ITT INDICATOR N3, ITT (CONTROL FAULT ONLY)
• OIL TEMPERATURE HIGH	INDICATOR T_{OIL}
• OIL PRESSURE LOW	INDICATOR P_{OIL}
• ROTOR UNBALANCED	ALL ACCELEROMETERS, NARROW BANDS
• VIBRATION EXCESSIVE	ALL ACCELEROMETERS, HIGH BAND
• ANTI-ICE FLOW LOST	ANTI-ICE CONTROL SWITCHES ANTI-ICE FLOW SENSOR SWITCHES
• MANUAL CONTROL MODE	MANUAL MODE SIGNAL
• • ALARM VALID	MONITOR SELF-TEST AND PARAMETER VALIDITY CHECKS

SPA 4762-10A

MONITOR FUNCTION: MECHANICAL TREND

CONDITION	PARAMETERS USED
• ROTOR UNBALANCE TREND	ACCELEROMETERS, CONTROL MONOPOLES DEVIATION/TREND
• VIBRATION LEVEL TREND	ACCELEROMETERS DEVIATION/TREND

SPA 4762-12X

MONITOR FUNCTION: PERFORMANCE

CONDITION	PARAMETERS USED
• TEMPERATURE MARGIN LIMIT	CONTROL N1, T2, ITT (COMPUTED FLAT RATE MARGIN)
• TEMPERATURE RATIO TREND	CONTROL N1, T2, ITT: DEVIATION AND TREND
+ FUEL FLOW TREND	INDICATOR WF, CONTROL, N1, T2, AIR DATA PT, T2: DEVIATION AND TREND
+ SPEED RATIO TREND	CONTROL N1, N2, N3, T2 DEVIATION AND TREND
= EARLY DETECTION OF UNUSUAL ENGINE DAMAGE	CONFIRMATION OF INDICATION

SPA 4762 /A

TURBINE ENGINE FAULT DETECTION AND ISOLATION PROGRAM

(ADVANCED TRENDING ANALYSIS PROGRAM)

by

CHARLES A. SKIRA
Air Force Aero Propulsion Laboratory
WPAFB, Ohio

Seventh Annual Tri-Service Meeting on Aircraft
Engine Monitoring and Diagnostics

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee

December 5-7, 1978

HIGHLIGHTS

A new research and development program in the turbine engine diagnostics area has recently been initiated by the Air Force Aero Propulsion Laboratory and is discussed here. The objective of this program is to develop the methodology and analytical tools for analyzing advanced turbine engine gas path parameters for the purpose of isolating and tracking component degradation. Specific objectives are: 1) to detect and isolate engine faults to the individual module level; 2) to indicate maintenance action (trim, overhaul, etc.); 3) to provide an indication of engine and module health status for improved logistics management; and 4) to provide the potential for trending and maintenance forecasting.

The techniques developed under this program will be developed from a general framework and shall be applicable to a broad class of turbine engines. The techniques and methodology developed shall be validated using actual engine data from four (4) advanced aircraft turbine engines. They are the P&WA F100 engine, the P&WA TF-30 engine, the GE TF34 engine and the DDAD TF41.

The program is a thirty-four (34) month seven person-year effort beginning in November 1978.

1.0 Introduction

1.1 Problem/Objective

Requirements for increased aircraft availability and improved aircraft readiness have placed a high premium on improving aircraft turbine engine maintenance. This problem is heightened by the fact that today's high performance aircraft turbine engine power plants are considerably more complicated (and more costly) than their predecessors.

Because of the huge acquisition and support costs of today's advanced turbine engines, more and more emphasis is being placed on developing new engine maintenance techniques for the purpose of reducing the total cost of onwership while at the same time ensuring overall fleet readiness.

Rising support costs for today's engines have dictated the need for maintenance improvements in two areas. The first area of improvements is in spare parts allocation. Because of high acquisition costs, there is increased emphasis on reducing the total number of spare parts in supply. However, when this is done, the risk of reducing overall operational readiness of a squadron or fleet is increased. Clearly then, there is a need for identifying the critical engine components--those that tend to wear out at a faster rate--and consequently optimizing the spare parts inventory and supply system function with respect to cost and aircraft availability. The second area of improvement involves reducing the engine/aircraft downtime--the total time to perform the required maintenance action and to return the aircraft to an operationally ready status. This requirement has lead to a new design philosophy for turbine engines that is geared to ease in maintenance (1).* The F15/F100 weapons system is a prime example where the entire engine can be removed from the aircraft in about twenty (20) minutes. The engine in turn has been designed such that the individual modules (fan, high compressor, combustor-high turbine, low turbine, and afterburner) could be easily removed for maintenance purposes. Some of these design considerations that were incorporated into the F100 were readily accessible, quick disconnect plumbing, strategically locating borescope and instrumentation ports, a simply unbolting arrangement of the case, and inclusion of the bearings as part of the individual module. Although these design changes can reduce downtime, they are of little value unless engine problems that require maintenance action can be recognized, diagnosed, and the faulty components quickly and accurately isolated.

Just how the need for improved fault diagnosis and fault isolation techniques and the need for improved inventory management has come about can be realized by considering the current turbine engine maintenance process and information flow within the Air Force is shown

*Numbers in brackets refer to the technical references.

in Figure 1. The engine maintenance process begins with some maintenance activities at the base or field level. These activities include flight-line maintenance activities such as visual (borescope) inspection, engine trim, troubleshooting and some minor flightline repair and fixes. Intermediate or support maintenance such as engine module replacement or engine accessory removal/replacement is also done at the base level at the Jet Engine Intermediate Maintenance (JEIM) Shop. The requirement for improved fault detection and isolation to the individual module level is, then, a base level requirement.

Major engine module repair or complete overhaul is done at the engine overhaul facility or depot. The overall logistics management of the maintenance process resides within the logistics center. It is here that the requirement for improved spare parts supply and inventory management originates. It should be pointed out that this function relies heavily on accurate, reliable data from the field and the overhaul facility to be effective.

For the purpose of this program, engine data indicative of the engine functional condition or mechanical status shall be called engine condition monitoring (ECM) data. This is a rather broad definition and includes data from some well developed and proven techniques such as oil analysis (SOAP, ferrography), engine vibration analysis, limit exceedence data, and accessory component monitoring to name just a few, plus data from some not as well developed techniques such as event history recording (EHR), gas path performance monitoring, performance trending, and low cycle fatigue (LCF) monitoring.

If accurate and dependable condition monitoring data that was indicative of the performance level or health status of the individual module were available, both requirements for improved base level maintenance and improved logistics management could be satisfied. Of the engine condition monitoring techniques, only gas path analysis has the potential for providng accurate and dependable component module performance data.

The objective of this research program is to develop improved engine condition monitoring techniques by developing the methodology and analytical tools for analyzing advanced turbine engine gas path parameters for the purpose of isolating and tracking gas path component degradations.

2.0 Scope

2.1 Duration

This will be a thirty-four (34) month (thirty-one (31) month technical effort), three-phase, program designed to develop the methodology and analytical tools for performing gas path analysis of turbine engine components. For discussion purposes, a program milestone/task chart is shown in Figure 2. As discussed previously, the development of such a technique must satisfy the requirements of and the constraints imposed by the current Air Force maintenance process. Therefore, the first phase of this program shall result in a definition of the system requirements, and guidelines. Phase I shall be a six (6) to nine (9) month effort during which the contractor shall perform a systems operational analysis of the current Air Force maintenance process. During this survey, the contractor shall determine the using command requirements for engine condition monitoring techniques and consequently the detailed requirements for gas path analysis. In addition, the contractor shall define several approaches for integrating gas path analysis techniques into the maintenance system. This will involve system software and hardware definitions, specifications and their subsequent impact on the maintenance process.

Phase II shall be approximately a sixteen (16) month effort to be initiated about midway through Phase I. During this phase, the contractor shall develop the analytical framework and software algorithms for performing gas path analysis and performance trending. The contractor shall be required to validate and verify his software algorithms by demonstrating their functional capability against simulated and actual aircraft engine data.

Phase III shall be a fifteen (15) month effort during which the contractor shall refine the system software to be user oriented and prepare supporting documentation. During this time, the contractor shall also determine the feasibility of integrating these techniques into the current maintenance system and shall also define and prepare the necessary hardware specifications to accomplish this task.

2.2 Limitations/Ground Rules

As has already been alluded to, the area of turbine engine diagnostics and condition monitoring is complex and encompasses several different and distinct methodologies. It is, therefore, imperative that firm guidelines and ground rules be established to define the exact nature of this work effort.

The system operational analysis effort during Phase I shall address the current practices and near time future requirements of the Air Force maintenance process. The recommendations and requirements definition resulting from this effort shall be constrained to conform to the existing and projected hardware, manpower, and facility limitations. Recommendations concerning development and implementation practices or the acquisition of new maintenance hardware, such as data processing equipment, shall carefully consider the associated cost, maintainability, and training requirements of such a system.

The development of the methodology and analytical effort during Phase II and III shall consider turbine engine gas path performance analysis for military fighter engines only. The methodology and software developed under this effort shall be required to satisfy three criteria. First, the techniques are to be developed from a general point of view rather than for a specific application. During Phase II, the contractor shall be required to demonstrate the flexibility of his approach by applying his methodology to at least two (2) engine systems. Secondly, the approach is to be well documented, well understood and mathematically tractable (derivable). Third, the resulting methodology and software is to be Air Force (government) owned, operated, and ultimately maintained.

The resulting methodology and software shall be required to perform fault detection and isolation to the individual engine module level. The output of such an algorithm shall indicate the need for maintenance action such as trim, overhaul, borescope check, health status of the engine and/or modules, etc. The methodology shall also provide the potential for performance trending and maintenance forecasting.

2.3 Data Base

Engine environmental and gas path data shall be provided by the government and shall be made available to the contractor through the CDC 6600 computer system at WPAFB, Ohio. Additional data to be provided, if necessary, include sensor data, data acquisition specifications, maintenance data, simulation data, and processor data.

Data from the following candidate engine systems shall be available under this program: the P&WA F100 turbofan engine; the DDAD TF41 turbofan engine; the GE TF34 turbofan engine; and the GE TF39 turbofan engine.

Because of the nature and the quality of the data available under the F100 Engine Diagnostic Engine (EDS) program, the P&WA F100 engine shall be a prime candidate. Data from the flight test phase of the F100 EDS program shall be provided with special assistance from the McDonnell Douglas Corporation.

3.0 Approach

During normal operation, aircraft gas turbine engines are subject to wear out and deterioration which may result in a degradation in performance. Problems such as excessive tip clearances, deformed compressor and turbine blades (caused by wear, erosion, corrosion, creep, foreign object damage or dirt accumulation), inefficient combustion, and lost or broken blades will affect the component aerodynamic characteristics to such a degree as to alter the overall engine thermodynamic performance. The aim of gas path performance analysis is to associate a change in the performance level of a gas path component, such as the turbine, compressor, or combustor, with an observed change in the thermodynamic performance cycle.

Gas path performance analysis is certainly not the endall to turbine engine diagnostics. However, if done properly, it can be a valuable part of any comprehensive turbine diagnostic system. Smetana (2) discusses some of the capabilities and limitations in his review of turbojet gas path analysis. Through gas path analysis it is possible to:

(1) detect a transducer malfunction,

(2) determine, approximately, if the thrust setting is correct for a given control setting,

(3) determine if the fuel comsumption is as it should be for a control setting and thrust output,

(4) determine in which major component a fault lies,

(5) predict maintenance requirements based on an extra polation of engine component performance history

Since gas path analysis does not give a good picture of the condition of the engine components that do not interact with the gas stream, it is not possible to:

(1) detect failures or leaks in the oil system unless excessive spool friction results,

(2) detect failures or problems in the accessory system,

(3) detect bearing failures unless they also result in excessive spool friction,

(4) detect creep or fatigue in any mechanical element unless such failures result in a change in the boundaries of the flow path

As Smetana points out, all gas path analysis methods have the fundamental goal of allowing fault isolation on the basis of measured and/or calculated values of a selected set of parameters, which can be considered prime indicators of engine condition at the component level. Ideally, these parameters would be the various component efficiencies, pumping capacities, and effective areas throughout the gas path. However, no suitable sensor or measuring technique is available for measuring these parameters directly. Therefore, they must be synthesized or computed on the basis of some available measurements in accordance with some convenient thermodynamic analysis technique.

The general gas path analysis problem can be formulated as follows:

$$\dot{x} = f(x, u, \Theta) + w(t) \qquad (1)$$

$$y = h(x, u, \Theta, \phi) + v(t)$$

where: x = engine state variable

u = control input variable

Θ = engine component health parameters

w(t) = engine disturbance (uncertainty)

y = measured (observed) variable

ϕ = measurement error parameter

v(t) = measurement disturbance (uncertainty)

Equation (1) represents the non-linear engine dynamics. As is shown, they are a function of the engine state, such as temperatures, pressures, and speeds, the control inputs such as fuel flows, nozzle areas, and geometry position, and the engine component health parameters such as efficiencies, effective area, and pressure losses, etc. Disturbances which might also affect the engine such as inlet temperature and pressure variations, unsteady flow due to nonideal mixing, and variations in temperature and pressure flow profile are representated by the term W(t).

Equation (2) represents the measurement process. The measurements are a function of the engine state, control input, health, and measurement error parameters such as gain misadjustment, offset, vibration sensitivities, temperature effects, etc. Uncertainties in the measurement due to measurement noise, quantization, etc., are represented by the term v(t).

Equations (1) and (2) are a general representation of the gas path analysis problem. All previous efforts in turbine engine gas path analysis have been formulated from this general framework with some simplifying assumptions. The earliest work was done by Cockshutt (3) of the National Research Council of Canada. The real problem of condition monitoring and fault detection and isolation becomes one of solving these equations for the component performance parameters, Θ.

Early approaches involved an implicit solution for the engine health parameters, Θ. These early techniques would observe a shift in the measured output, and through the application of some fault free logic, attempt to associate these changes in the observed cycle parameters with a shift or change in the engine component health parameters. For complex engine cycles this approach becomes unattractive due to the excessive complexity of the fault tree logic.

More recent approaches (4), (5), (6), have concentrated on the development of an explicit solution of the system equations for the fault detection and isolation engine health parameters. The methodology developed under this program will aim toward the development of a closed form solution for the individual component health parameters. There are several technical considerations to be addressed which turn out to be subproblems associated with the development of a closed form solution to the system equations.

In order to develop condition monitoring logic of any kind, a precise definition of the system requirements is needed. The system performance requirements will impose bounds on the selection of the measurement system and help to define the computational requirements of the logic algorithm (7). As mentioned in Section 2.0, the first phase of this program will define the system requirements based on the future needs of the Air Force Logistics Command (AFLC) and the Tactical Air Command (TAC). However, for the purpose of this procurement, the fault detection algorithm shall be designed and developed to detect and isolate engine faults to the individual component module level.

Other problesm plaguing gas path condition monitoring include the selection of a suitable criteria for fault detection (8), and the introduction of measurement instrument and actuation system error (7). Variations in the engine operating point and non-linearity within the engine will also introduce errors which may significantly affect the accuracy of gas path analysis (9).

Another important aspect of fault detection and isolation is associated with the computational algorithms. Namely, the software logic must be computationally efficient, mathematically precise, and above all, flexible.

Performance trending as addressed in this effort shall attempt to establish a correlation between the engine helath parameters and a suitable independent parameter or set of parameters. In order to reliably use these results for engine health prediction or maintenance forecasting, it is important that this correlation result in a prediction model that is accurate and repeatable. Since the engine health parameters are calculated from the fault detection and isolation algorithm, it is important that this algorithm yield valid results. Likewise, the independent parameters must be readily available or easily accessible from existing engine measurements.

4.0 Program Status

Offerors were permitted to bid on Phase I or Phase II and III separately or on all three phases together. The following companies submitted proposals:

Organization	Proposed Effort
System Control Inc (SCI)	All Three Phases
Dynamics Research Corporation	Phase I only
Pratt & Whitney Aircraft (GPO)	All Three Phases
Boeing Company, Seattle WA	Phase I only
General Electric, Evendale OH	Phases II and III only

On 15 November 1978, a contract was awarded to Systems Control Inc, Palo Alto CA. A contract with McAir has been negotiated and will be awarded shortly.

References

1. Edmunds, David B., "Modular Engine Maintenance Concept Considerations for Aircraft Turbine Engine", paper presented at the SAE Aerospace Meeting, Los Angeles, CA., November, 1977.

2. Smetana, F. O., "Turbojct Engine Gas Path Analysis", AGARD Conference Proceeding No. 165 on Diagnostics and Engine Condition Monitoring, April, 1974.

3. Cockshutt, E. P., "Equilibrium Performance Analysis of Gas Turbine Engines Using Influence Coefficient Techniques," National Research Council of Canada, 1967.

4. Urban, L. A., "Gas Path Analysis Applied to Turbine Engine Condition Monitoring," Journal of Aircraft, Vol. 10, No. 7, 1973.

5. Kos, J. M., "Multiple Fault Gas Path Analysis Applied to TF30P408 Engine Data," AD785265, 1974.

6. DeHoff, R. L., and Hall, W. E., "Advanced Fault Detection and Isolation Methods for Aircraft Turbine Engines", ONR-CR-215-245-1, April, 1977.

7. Gupta, N. K. and Hall, W. E., "Design and Evaluation of Sensor Systems for State and Parameter Estimation", AIAA Paper No. 771050, August, 1977.

8. Willsky, A. S., "A Survey of Design Methods for Failure Detection in Dynamic Systems", MIT Electronic Systems Laboratory report ESLP633, November, 1975.

9. Gupta, N. K. and Hall, W. E., "Model Structure Determination and Test Input Selection for Identification of Non-Linear Regimes", ONR-CR-215-213-5, February, 1976.

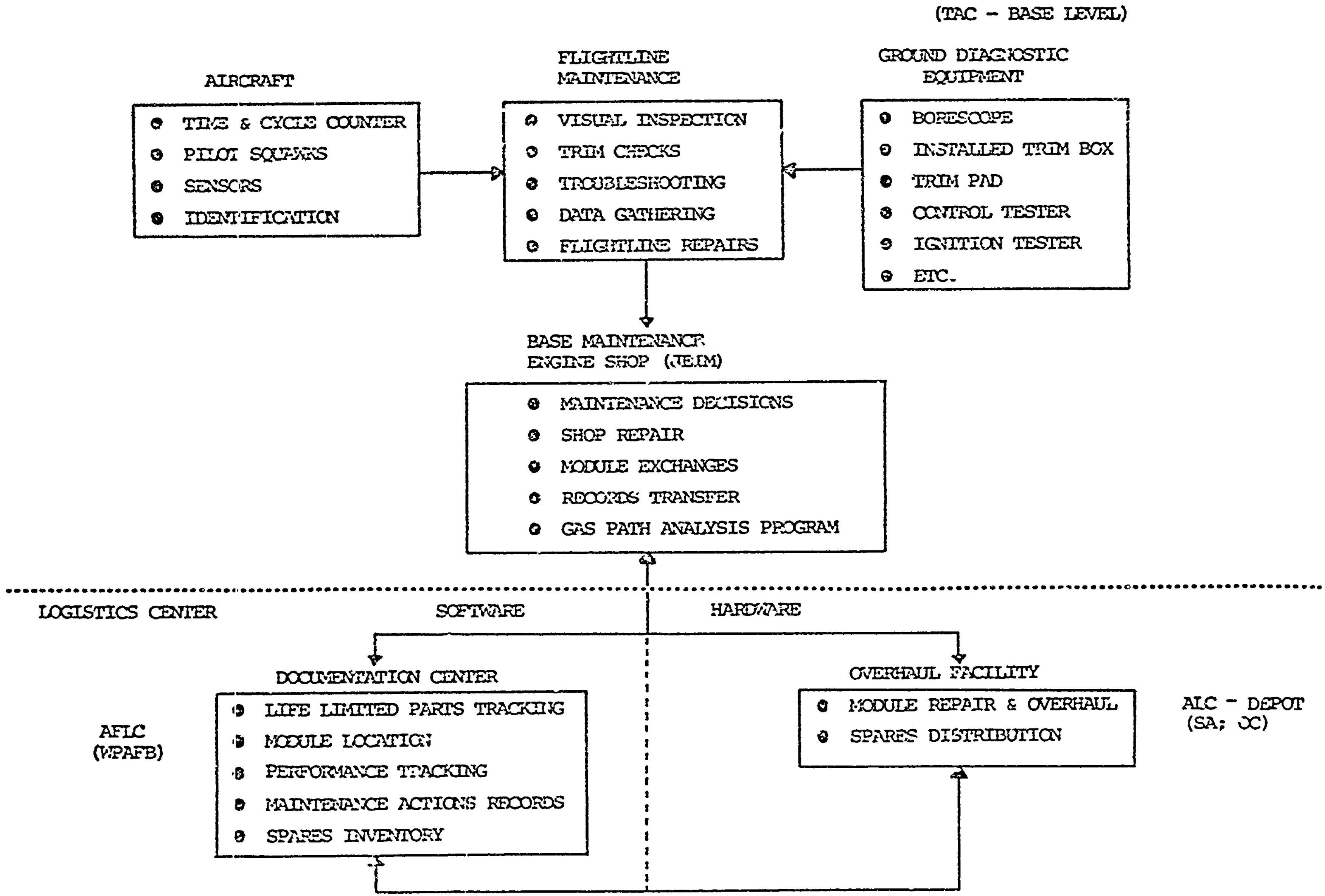

(TAC - BASE LEVEL)
AIRCRAFT
TIME & CYCLE COUNTER
PILOT SQUAWKS
SENSORS
IDENTIFICATION
FLIGHTLINE MAINTENANCE
VISUAL INSPECTION
TRIM CHECKS
TROUBLESHOOTING
DATA GATHERING
FLIGHTLINE REPAIRS
GROUND DIAGNOSTIC EQUIPMENT
BORESCOPE
INSTALLED TRIM BOX
TRIM PAD
CONTROL TESTER
IGNITION TESTER
ETC.
BASE MAINTENANCE ENGINE SHOP (JEIM)
MAINTENANCE DECISIONS
SHOP REPAIR
MODULE EXCHANGES
RECORDS TRANSFER
GAS PATH ANALYSIS PROGRAM
LOGISTICS CENTER
SOFTWARE
HARDWARE
AFLC (WPAFB)
DOCUMENTATION CENTER
LIFE LIMITED PARTS TRACKING
MODULE LOCATION
PERFORMANCE TRACKING
MAINTENANCE ACTIONS RECORDS
SPARES INVENTORY
OVERHAUL FACILITY
MODULE REPAIR & OVERHAUL
SPARES DISTRIBUTION
ALC - DEPOT (SA; OC)

FIGURE 1

F33615-78-C-2062

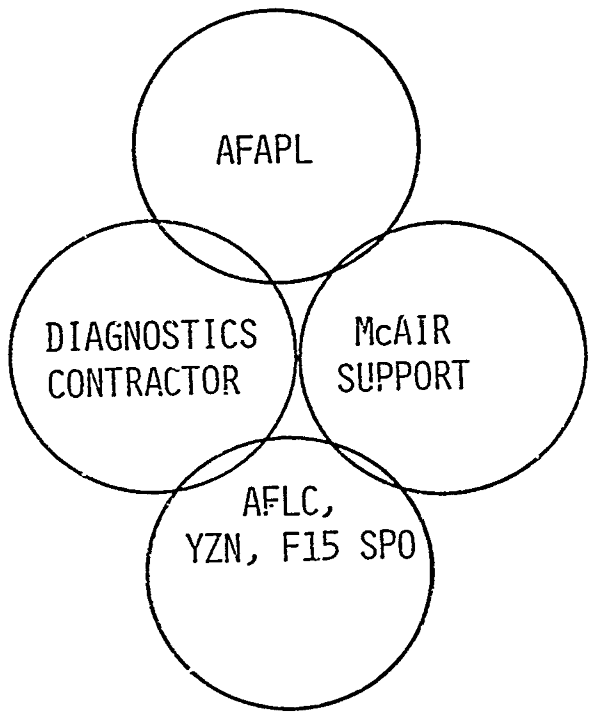
ADVANCED TRENDING ANALYSIS PROGRAM

TASK	TITLE	FY 78 / CY 78 – FY 81 / CY 81
1	Phase I System Requirements Definition	
1.1	1. Maintenance and Logistics System Analysis	
1.2	2. System Requirements Definition	
	Technical Review Meeting	
	Coordination Meeting	
DI-S-3591A	Draft Final Report – Phase I	
DI-S-3591A	Final Report – Phase I	
2	Phase II Methodology Dev	
2.1	1. Gas Path Performance Algorithm Development	
2.2	2. Trending Analysis	
2.3	3. Validation/Verification	
3	Phase III Implementation Analysis	
3.1	1. Software Refinement	
3.2	2. Systems Integration Analysis	
3.3	3. Hardware Requirements	
	Coordination Meeting (Oral)	
DI-S-3591A	Draft Final Report-Phase II&III	(32 MAC)
DI-S-3591A	Final Report-Phase II&III	(34 MAC)
DI-M-3410/M	Users Manual – FDI (DRAFT)	
"	" " " (FINAL)	
DI-A-3007	Program Schedule	NO 1,40 DAC AND MONTHLY THEREAFTER
DI-A-3002	R&D Status Report	NO 1,40 ADD-MONTHLY THEREAFTER
DI-F-3204	Alternate Manag. Summary Rept.	NO 1,40 DAC AND MONTHLY THEREAFTER
DI-A-3025B	Abstract for New Technology	AS REQUIRED

AFSC FORM JUL 1851

FIGURE 2

ADVANCED TRENDING ANALYSIS PROGRAM



ADVANCED TRENDING ANALYSIS PROGRAM FUNCTIONAL RESPONSIBILITIES

AFAPL ROLE

- CONTRACT ADMINISTRATION AND PROGRAM MANAGEMENT

DIAGNOSTICS CONTRACTOR ROLE (SYSTEMS CONTROL INC)

- GAS PATH ANALYSIS
- TRENDING ANALYSIS
- OPERATIONAL SYSTEMS ANALYSIS

MCAIR ROLE

- EDS DATA SUPPLY
- LOGISTICS/MAINTENANCE ANALYSIS TEAM MEMBER
- EVALUATE/CRITIQUE RESULTS

AFLC, YZN, F15 SPO ROLE

- DATA SOURCE
- LOGISTICS/MAINTENANCE ANALYSIS TEAM MEMBER
- EVALUATE/CRITIQUE RESULTS

TURBINE ENGINE FAULT DETECTION AND ISOLATION PROGRAM

OBJECTIVE

TO DEVELOP THE METHODOLOGY AND ANALYTICAL TOOLS FOR ANALYZING ADVANCED TURBINE ENGINE GAS PATH PARAMETERS FOR THE PURPOSE OF ISOLATING AND TRACKING COMPONENT DEGRADATIONS FOR IMPROVED ENGINE CONDITION MONITORING.

APPROACH

DEVELOP METHODOLOGY FROM A GENERAL FRAMEWORK. VALIDATE TECHNIQUES USING ACTUAL ENGINE DATA.

SCOPE

3-PHASE, 34-MONTH EFFORT (7 PERSON YEARS)

- PHASE I - SYSTEM REQUIREMENTS DEFINITION
- PHASE II - METHOLOLOGY DEVELOPMENT
- PHASE III - IMPLEMENTATION ANALYSIS

CONTRACTOR

SYSTEMS CONTROL INC - PRIME

MCDONNELL-DOUGLAS - EDS DATA SUPPORT

REQUIREMENTS

GAS PATH PERFORMANCE ANALYSIS

MILITARY ENGINE APPLICATION

SATISFY TAC NEEDS

- FAULT DETECTION AND ISOLATION TO THE MODULE LEVEL
- INDICATE MAINTENANCE ACTION (TRIM, OVERHAUL, HEALTH STATUS, HISTORY)

SATISFY AFLC NEEDS

- PROVIDE ENGINE AND MODULE HEALTH STATUS
- PROVIDE POTENTIAL FOR TRENDING AND MAINTENANCE FORECASTING

TECHNIQUES TO BE FLEXIBLE (ADAPTABLE TO DIFFERENT ENGINES)

APPROACH WELL DOCUMENTED (TRACTABLE, WELL UNDERSTOOD)

SOFTWARE TO BE AIR FORCE OWNED, OPERATED AND MAINTAINED

DATA BASE

ENGINE DATA SHALL BE PROVIDED BY THE AIR FORCE AND SHALL BE ACCESSIBLE THROUGH THE WPAFB CDC 6600 COMPUTER SYSTEM.

POSSIBLE DATA SOURCES

F100 EDS FLIGHT TEST DATA	(ASD/YFA)
TF41 AMT DATA	(AFAPL)
F100 M-37 STAND DATA	(ASD/YZN)
A10/TF34 FLIGHT TEST DATA	(AFLC/LOP)
A-7D/TF41 FLIGHT TEST DATA	(AFLC/LOP)

ENGINE DATA

ENGINE ENVIRONMENTAL AND GAS PATH DATA

SENSOR DATA

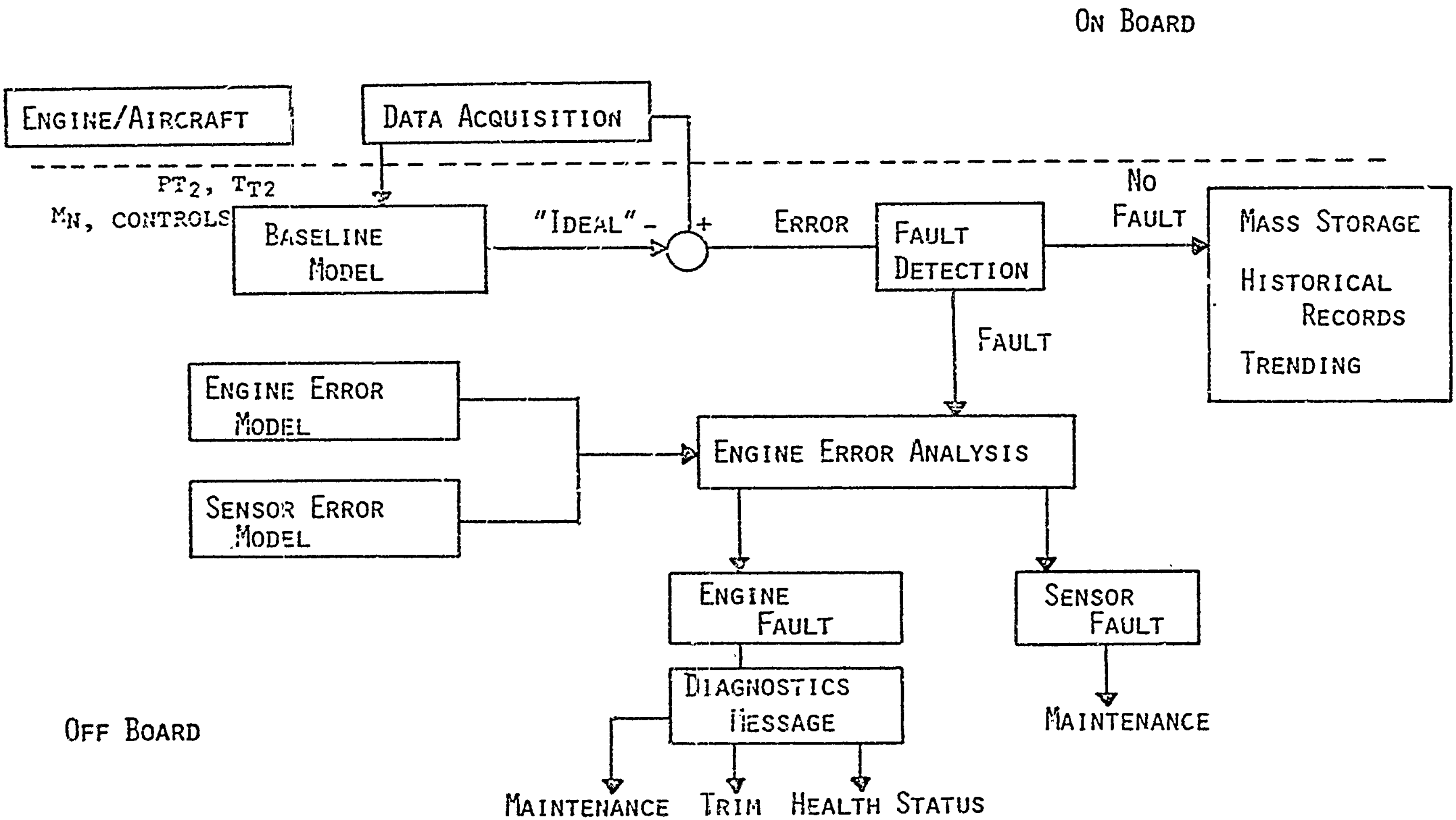
DATA ACQUISITION SPECS

MAINTENANCE DATA

SIMULATION (STATUS DECK) DATA

PROCESSOR SPECS

FAULT DETECTION AND ISOLATION SENARIO



FEATURES OF METHODOLOGY

ADVANCED FILTERING -- DATA SMOOTHING

DATA COMPRESSION TECHNIQUES -- DE-TRENDING, MOVING AVERAGE

DECISION THEORY -- HYPOTHESIS TESTING USING STATISTICS

SYSTEMS MODELING -- GENERIC BASELINING VS. CUSTOM BASELINE

SENSOR ERROR MODELING -- IDENTIFYING MAJOR CONTRIBUTORS TO SENSOR ERROR

PARAMETER ESTIMATION -- PROCESS OF SOLVING SYSTEM EQUATIONS TO OBTAIN ENGINE HEALTH PARAMETER ESTIMATES

LIFE USAGE AND ACCOUNTING

W. TROHA

AFAPL, WPAFB, OHIO

HIGHLIGHTS

A study of cargo, bomber, fighter, and flight test data vs theoretical temperature cycles. No agreement on an engine cycle. AFAPL uses stop-run-stop. Others use PLA cycles and considers flight recording of N_1, EGT, PLA, Mn, OAT, Alt. Mathematical analysis indicates that by monitoring 7 parameters a 95% confidence level of usage tracking and life accounting is attainable.

LIFE USAGE TRACKING AND ACCOUNTING

Recent AF Aero Propulsion Laboratory programs have demonstrated the feasibility of using continuous recorded flight data to economically define engine life. The demonstrations also defined procedures to account for specific component hardware requirements needed to meet operational and logistic objectives. The briefing will discuss the development and demonstration of these capabilities with two examples: the YF17/YJ101 and the YC14/CF6. These programs are unique since they represent two different development approaches: the introduction of a new engine into a new airframe (YF17/YJ101), and the use of a "mature" commercial engine in a new airframe (YF14/CF6). Although the parameters recorded were similar in both programs, the data reduction and analysis procedures differ because of the experience base of the two engines.

YF17/YJ101

During the YF17/YJ101 prototype program, a significant effort was undertaken to collect and analyze continuous (approximately one data point per second) flight recorded data at both General Electric (GE) and the Aero Propulsion Laboratory (APL). The data was used to (1) define component life usage rates due to creep/stress rupture of the HPT blade, thermal fatigue of the HPT vanes and low cycle fatigue of the fan disk; (2) verify the assumed maximum turbine temperature operating time used to define the maintenance intervals; and (3) establish an acclereated ground engine simulated mission test cycle. This was accomplished at GE by using strip chart recordings of related engine parameters (power setting, exit gas temperature, Mach number, altitude and inlet temperature). Concurrently, a computer program was written at APL to reduce digitized magnetic tape flight data into an engineering format for defining engine life usage--amount of time at temperature and cyclic level changes.

As with all flight data collection and analysis, the key to a successful effort is organization of the data and fast turnaround. The first part was accomplished by dividing the flight data into thirteen categories. Up to four sample flights were randomly selected for each category, depending upon the percent of aircraft flight time. This represented 19 flights, 14 hours of operation and over 800 engine power changes. In addition, power usage data was collected for installed and uninstalled engine ground running (green runs, break-in, Edwards test cells and aircraft ground running). The percent of run time for each of these conditions is: 2% factory, 9% Edwards test cells, 31% installed ground running and 58% flight. As can be seen from these numbers, ground running represents a significant portion of total engine operating time. This is a typical condition, and is not unique to this system.

Review of the flight test data shows significant differences from original projections. For a typical air combat maneuver, the time at various power settings and number of cyclic changes when compared to projected usage shows that: the total mission time is almost double; time spent above 50% of power is increased from 30% to 90%; cyclic power changes are increased by a factor of eleven. In general, the actual power usage represents an increase in severity of 60% to 80% over projected usage.

During the flight test program, the engine operated 270 hours before removal from the aircraft due to HPT blade necking. Using flight-recorded data, it was determined that if the engine had been used for air combat maneuvers 100% of the time, the engine would have only flown 89 hours before the HPT bucket would "neck" and/or crack. Using the aircraft with external stores to simulate bombing drops, the cyclic damage was 3.2 times more severe than the average mission mix. It is significant to note the predominant failure mechanism for the air combat mission is time at temperature, thus affecting the high temperature components, whereas, for the simulated bombing drops it is predominantly cyclic--affecting cyclic sensitive components such as disks. It was also determined that missions which are typically flow to checkout system operational capability have both high cyclic and time at temperature damage exposure. These differences in mission mix and failure mechanism have a significant effect on projecting hardware life, mean time between failure, scheduled and unsheduled engine removals, maintenance man-hours, hardware consumption rates, supply requirements and scheduling of maintenance/operational readiness actions. Without recorded flight usage data to perform these types of analyses, engine usage projections have been shown to be mere guesses, and represent minimal credibility in defining AF maintenance and logistic functions.

Automated reduction of engine flight data was accomplished by generating a computer program to read and organize engine parameter data from digital magnetic tapes. Data recording is initiated before the engine is started, and stopped after the engine shutdown. The data is read from magnetic tapes and organized into the amount of time at various engine conditions, the number of cyclic level changes, and acceleration/deceleration times. Engine parameters programmed for data reduction were: time, Mach number, altitude, turbine exit gas temperature, power level angle (PLA), burner pressure, fuel flow, core and fan rotor speeds. Data reduction of other parameters is a simple programming procedure. The major organizational procedures of the computed data reduction program are:

- o Begin data analysis when the engine is running--not when the recorder is turned on.
- o Search the data tape for desired engine parameters to initialize variable.
- o Count the amount of time within defined parameter levels. As an example, PLA was divided into 5% increment levels between 80% and 100% power (where life sensitivity is more severe), and 10% increment levels between idle and 80% power. These increment levels depend upon the desired sensitivity.

- o For cyclic sensitivity parameters: determine the level of initial acceleration or deceleration, the level of change for each, and the amount of time for the accel and decel to occur.

- o Data is printed in a format defining: (1) the amount of time within each event, and (2) the number, level and amount of time for each cyclic excursion (accel or decel). For each data set (sortie) a summary total accumulation of events, time and percent of each is provided.

Organization of the flight recorded data into this format allows it to easily be used for defining engine and individual component operating conditions, life/usage severity, and/or simulated mission endurance test cycles. Maintaining the data in discrete mission categories allows one to define the impact of specific usage (air combat, bomb drops, training, etc.) and/or an average usage related to actual or projected mission mix. This data transfer procedure has been used on several programs since its initial development, and found to be simple and inexpensive. The ease of using these types of computerized data reduction procedures has brought important information to the design engineers which was too expensive to organize in the past.

Flight data collection and analysis of continuously recorded engine data should be a routine procedure within every development program. It should be performed by the engine contractor from initial flight test through Operational Test and Evaluation (OT&E). The data will be used to provide the engine companies with sufficient information to correlate flight usage with field and factory failures, to define representative accelerated ground engine simulated mission test cycles, and to define the minimum number of recorded parameters needed to track engine hardware failure rates for maintenance/logistic and operational programming.

YC14/CF6

Flight data from the YC14/CF6 was recorded in a similar manner as the YF17/YJ101. Select engine parameters (Mn, Alt, OAT, PLA, T42, N1) were used to determine if the CF6 engine was being used more severly in the YC14 application than in commercial service. A sensitivity study was conducted to determine if the number of flight recorded data points (approximately one per second for each parameter) could be reduced while maintaining sufficient accuracy in the analysis. This was accomplished by calculating engine power usage severity (compared to an average commercial mission) by combining changes in PLA level from one to five degrees. The study showed that a change of five degrees in PLA represented about 6% in severity accuracy. From this it was determined that a data synthesis of three degrees in PLA was sufficiently accurate for this effort. The three degrees synthesis reduced the number of data points to be analyzed for a typical sortie by 37%. It should be recognized that the amount of data synthesis must be determined for each engine/airframe usage and required prediction accuracy.

A study was conducted to verify the analytical accuracy for predicting unscheduled engine removals (UER). This was accomplished using expected (not recorded) commercial missions and actual UER experience from 19 airlines, representing more than 2.75 million flight hours. The study showed the predicted UER accuracy to vary between 3 and 19% for short and long flight lengths, respectively.

The YC14/CF6 engine usage analysis was accomplished using synthesized data from 189 flights, representing 614 engine hours. When compared to commercial usage, the YC14/CF6 engine cyclic severity was shown to be three times as severe for some missions. The analysis showed that although some of the engine hardware would function equally well in either application, the components sensitive to cyclic power excursions (hot components and disks) would only last half as long in the YC14/CF6 application as in commercial maintenance scheduling.

Conclusion

The use of continuous flight recorded data to predict engine hardware failure rates, simulated mission test cycles, unscheduled engine removals, and differences between military and commercial applications has been demonstrated. Economical data reduction procedures have been successfully used to synthesis large amounts of flight recorded data. These procedures will continue to be expanded and used as the need to more accurately define and forecast maintenance intervals, parts supply requirements and operational/training increases.

WILLIAM A. TROHA
AF Aero Propulsion Laboratory
Turbine Engine Division

EDITORIAL NOTATIONS ON TOPICS WITHOUT PAPERS

NAVAL AIR SYSTEMS COMMAND WASHINGTON D.C.
Hans Kohler
Navy Ground Support Equipment for Engine Monitoring

The program is based on propulsion automated equipment (PATE) using ATLAS programming language. The program proceeds from data in ATLAS to an intermediate code to a translator to machine code to a computer to an input/output device to the unit (engine) under test (UUT). P&WA is developing a TF30 trim tester that uses PT7, N_2, N_1, TT4, TT7, and PLA.

NAVAL AIR SYSTEMS COMMAND
Andy J. Hess
A-7E Integrated Engine Condition Monitoring System (IECMS)

This system takes 40 engine parameters by adding only an additional 14 transducers to those existing on the engine. The aircraft ~~of two~~ squadrons have been modified for the ECMS and are currently on the carrier Kennedy. These are scheduled to return to Jacksonville NAS in March or April. A preliminary evaluation has shown a drop of 18% in engine removal rates, a reduction of 14% in cost per repair action of engines at the Aircraft Intermediate Maintenance level, significantly less secondary damage, and a general shift of repair action to a lower level of maintenance. ANG/Navy are currently working on a joint program for possible IECMS application.

Other Diagnostic Programs being considered by the Navy are manual programs for patrol aircraft and turbo props, performance trending by flight data and signature, low cycle fatigue, vibration frequency analysis, and solid state recorders to replace low reliability tape decks. Electronic fuel controls should be designed with diagnostic data connectors in place.

ARO, AEDC, TN
C. Wade Stevenson
TEMS Conceptual Engineering

ARO has made significant progress in the past year on equipment to test engines with programmed inlet air distortion. Pressure measured from a tap in the engine inlet are affected by the Mn and pressure altitude. A relationship of deltas in the IGV, LPT, HPT, and COMPR VS N_1, N_2, EPR, and SFC was presented. The goal is to define the most efficient technique to isolate defective line replaceable units (LRU) and provide the basis for automating the data interpretation and maintenance decision process.

CONCLUSIONS

All TEMS systems that are being currently tested provide a variety of deterioration and fault identifications as decision information for trending maintenance actions. However, highly valid identification of module components and LRU deterioration for fault isolation or trending requires considerable software advancements. There are many parameters and relationships in a turbine engine from which performance and efficiency may be computed. However, those which are meaningful, those which can be measured with the required accuracy and how the signature pattern of each of the pertinent major components, modules, or LRUs must be determined and implemented for each engine model.

As a minimum, monitoring porvisions for installation of the required sensors need to be designed into the engine. Because of both mechanical/electronic interferences, the installation of sensors on post-production engines poses many difficult to highly impractical tasks. Processing the sensor outputs and comparing the preset levels requires identification of specific signal ranges of interest or else the incorporation of a lot of computer capability to cover all aspects of the signal and to provide the required accuracies. Solid state devices (computers, multiplexers, signal processors) require a protected environment for accurate and reliable operation. Engine signatures should be determined in the development phase to provide parameters for a TEMS systems that is capable of being updated from operational experience.

The TEMS state-of-the-art appears to be able to provide a satisfactory measure of the following benefits in order of decreasing capability.

a. Improved operational readiness status.

b. Improved flight safety.

c. Reduced major maintenance by detecting engine deterioration early and identifying the LRU which can be scheduled for convenient replacement.

d. Reduced fuel consumption by less engine ground runs and maintained optimal operating efficiency.

Knowledge gained from experience in pattern recognition, precise selection of data to be monitored, improved sensor capability and installation practices, improved signal processing and recording required to feed useable information to all levels of maintenance, operations and support decision levels, need advancement to attain the goals of reliability centered analysis and the practice of large cost avoidances through the practice of "on-condition" maintenance instead of "hard time" inspections and overhaul.

Perhaps the most important factors embodied in any TEMS is the improvement of readiness which requires all levels of maintenance and support personnel to readily understand and use the information to better make decisions and accomplish his job. This also infers that a brief training period may be required to effectively use the TEMS and the information provided thereby.

OPEN DISCUSSIONS AND COMMENTS:

Wade Stevenson, ARO, Math models take lots of computer space.

Lt Col Pettigrew, ASD, Deterioration plots usually have a double hump rather than a normal declining curve. This emphasizes the need to get enough data to establish a method of pattern recognition.

Keith Hamilton AFAPL, We need to coordinate and integrate existing engine controls, flight controls, air data system and cockpit instruments. Additions would include vibrations, bleed air flow, and coordination with NAVY ULAIDS on the solid state recorder development.

Col Van Horn and Sgt Pobanz, Hq TAC, Module isolation was requested in 1975. The F-16 has 26 LRUs. The F-18 engine includes TEMS equipment. The repair in warranty (RIW) concept has merit. A DOD TEMS organization should be established to coordinate, like SOAP, all TEMS efforts rather than continue existing duplications.

Col Streett, Hq SAC, TEMS is like a candy store with an announced "new candy". Salesmen are spell binders portraying concepts as off-the-shelf items. The prospective customers are characteristically gullible.

What is an engine cycle? Many opinions such as start-to-stop; pressure; idle to power to idle: theoretical mission: turbine inlet temperatures; fuel flow; thrust. ASD/YZE will provide a definition.

Get TEMS in the GOR (now SON - Statement of Need) and require each engine manufacturer to provide TEMS data along with the developed engine.

ITEMS OF CONCERN INCLUDE:

Complete definition of engine operating parameters to be based upon monitoring and diagnosis requirements for each individual engine and its problems.

Total system recording, interface and software programming costs.

Economical and effective choice of the best "mix" of recording and interface systems available or to become available.

Engine manufacturers' definition of requirements for recording and processing engine operating parameter data compared to normal values should be provided.

Manhours requirements needed to process, interpret, and use the TEMS data under the adopted maintenance concept should be defined.

Life cycle cost comparison of all available approaches for TEMS applications should be made.

MEMO TO YZE (LT COL PETTIGREW) 1 Aug 79

SUBJECT: Definition of an Engine Cycle

1. This letter is in response to your request for a definition of "What is a cycle?" Apparently, this question had caused confusion at the Seventh Annual Tri-Service meeting on Aircraft Engine Monitoring and Diagnostics held last fall.

2. For all turbojet and turbofan engines, low cycle fatigue (LCF) damage occurs when there is an alternating stress. Alternating stresses are due to engine RPM excursions and/or thermal induced stresses, both caused by throttle transients.

3. When tracking LCF damage, throttle transients are categorized into two basic EVENTS:

a. Zero-max/intermediate - zero (often called sortie cycle, takeoff cycle, or major cycle)

b. Idle - Max/intermediate - idle (often called partial cycle, touch and go cycle, or minor cycle)

4. LCF counters and ETTRS are used to track the above events by tripping gates for RPM or temperature excursions.

5. Cycles are usually expressed in terms of zero-max-zero events or major cycles. Each component will feel the damage of these events to varying degrees in terms of major cycles. Analysis and test can determine the maximum number of major cycles each part can withstand. This is called the major cycle limit. Minor cycles (idle-max-idle) also consume parts lives and have a limit. Minor cycles are related to major cycles by a ratio of major cycle limit to minor cycle limit which is called a "K" factor. Total fatigue damage a part has felt can be equated: total part cyclic damage = major cycles + K (minor cycles).

WILSON R. TAYLOR
Aerospace Engineer
Structural Durability Division

CYCLE DEFINITION

PROPOSED ACTION. The definition of an engine cycle and common definition of terms used by the propulsion community has been discussed by a General Officers' Steering Group on Propulsion Management Enhancement. One of their ten Phase II enhancements actions was as follows:

a. Common Terms - In the past, misunderstanding regarding the definition of terms used by the propulsion community has occurred. Examples are the use of "mission cycles" to describe life limits of various components in lieu of the "TAC cycle" currently tracked by the G337 (F100 engine), and the MMICS. In addition, standardization and utilization of all terms used by the propulsion community would aid in communication and understanding and have potential benefits to specific activities such as the application of engine warranties. We proposed that AFM 400-1 be revised to include all terms used by the propulsion community. This coordinated effort of the propulsion community would provide a standardized glossary of terms for use by the government and contractor agencies.

Meanwhile, the two major engine contractors (PWA and GE) should be notified in writing of the need to specify hour and cycle limits in the terms currently being tracked by the using and supporting commands.

REF: DEPT OF TRANSPORTATION, FEDERAL AVIATION ADMINISTRATION, FS-320, INSTRUCTION 8310.4A, CHG 3.

The FAA recognizes three primary maintenance processes. (1) These processes are simply a means for classifying the way in which a particular aircraft element is maintained. Any one or any combination of these processes may be part of an operator's "reliability program."

The three primary maintenance processes have no self-implied order of importance. Each has its own place in an effective maintenance program. The right process is determined primarily by the design of the hardware and secondarily by the user's economics, not by any historical significance. To say it in another way, "Hard Time" is not the best because it was first - nor is "condition monitoring" the best, or the worst, because it was last.

A description of each primary maintenance process follows:

(1) Overhaul Time Limit or Part Life Limit - (HT) - this is a preventive primary maintenance process. It requires that an appliance or part be periodically overhauled in accordance with the operator's maintenance manual or that it be removed from service. These time limitations may be adjusted based on operating experience or tests, as appropriate.

(2) On Condition Maintenance - (OCM) - This is a preventive primary maintenance process. It requires that an appliance or part be periodically inspected or checked against some appropriate physical standard to determine whether it can continue in service. The purpose of the standard is to remove the unit from service before failure during normal operation occurs. These standards may be adjusted based on operating experience or tests as appropriate.

(3) Condition Monitoring - (CM) - This is a maintenance process for items that have neither "Hard Time" nor "On Condition" maintenance as their primary maintenance process.

CM is accomplished by having appropriate means of data collection and analysis by which an operator obtains information from the whole population of a system or item in service and uses this information to allocate this technical resources. A maintenance program that inclues "Condition Monitoring" must provide the following for the units maintained by this process:

(1) an effective data collection system. The operator shall use appropriate items from the following information sources as the basic elements of its data collection system:

(a) Unscheduled removals.

(b) Confirmed failures.

(c) Deficiencies observed and corrected but not otherwise reportable.

(d) Pilot reports.

(e) Sampling inspection.

(f) Functional checks

(g) Shop findings

(h) Bench checks

(i) Mechanical Reliability Reports

(j) Mechanical Interruption Summary, and

(k) Other sources.

(2) Appropriate reports, The operator's reporting system must include all aircraft covered by this maintenance program. It is the objective of this requirement to insure that the operator has an effective means of sensing the performance of all CM items or systems so that he can act effectively when required.

(3) A system for assessing the need for changes in aircraft maintenance or design and for taking appropriate action. Action will consist of appropriate provisions from:

(a) Actuarial or engineering studies to determine the need for maintenance program changes.

(b) Maintenance program changes involving the frequency and content of maintenance tasks.

(c) Aircraft, engine, or appliance modification.

FOLLOW-UP CORRESPONDENCE TO DECEMBER 1978 TRI SERVICE DIAGNOSTICS MEETING

1. Hq ATC/LG Ltr, 29 Dec 78, Subject "Engine Diagnostics"

2. Hq USAFE/LG Ltr, 22 Jan 79, Subject "Engine Diagnostics

3. Hq TAC/LG Ltr, 2 May 1979, Subject "Engine Monitoring/Diagnostics.

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR TRAINING COMMAND
RANDOLPH AIR FORCE BASE, TEXAS 78148

29 DEC 1978

LG

Engine Diagnostics

HQ USAF/LEY

1. After reviewing the report from the ATC representative to the Worldwide Engine Diagnostics Conference, I am concerned for the future of our diagnostic efforts. Specifically, the proliferation of diagnostic equipment and philosophy among the services could delay development of a truly workable system.

2. It appears to me that the major problems hindering development of engine diagnostic systems are a lack of central direction and visibility. Perhaps a solution to both problems is the formation of a Joint Task Force (JTF) for the development of engine diagnostics. A JTF formed at a suitable level, with tri-service representation to include the operating commands, could provide the centralized direction necessary to speed development of cost effective diagnostic systems.

3. Though ATC is not now involved in development of an engine diagnostic system, our experience with the T-38 Engine Health Monitor demonstrated the potential value of such a system. Our interest in further development of a cost effective engine diagnostic system remains high. In fact, we intend to specify fault isolation to specific engine modules as a requirement for the engines of the Next Generation Trainer (NGT). Further, we believe that the specifications for all future USAF engines should require that diagnostic probe mounting pads be installed during manufacture, even if a diagnostic system has not been designed for the engine. Building a new engine with pads to accommodate current state-of-the-art diagnostic probes would save great amounts of retrofit dollars later on.

4. In summary, the need for engine diagnostic systems has been established, yet their development is lagging basic engine development and increasing support costs. It's time we gave our support to a concerted diagnostic development effort aimed at increasing the maintainability of our new engines. You can be assured of total ATC support in this endeavor.

LAWRENCE D. GARRISON
Brigadier General, USAF
Deputy Chief of Staff, Logistics

Cy to: HQ SAC/LG
HQ TAC/LG
HQ MAC/LG
HQ AFLC/LO
HQ ADCOM/LG
HQ PACAF/LG
HQ USAFE/LG
ASD/YZ

Action: LGM
Info: LG/LL

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCES IN EUROPE
APO NEW YORK 09012

REPLY TO ATTN OF: LG

22 JAN 1979

SUBJECT: Engine Diagnostics (ATC/LG Ltr, 29 Dec 78)

TO: HQ USAF/LEY

1. USAFE fully supports the comments and recommendation made in subject letter. We understand that the on-board recorder/computer and sensors for the F-15/F-100 engine are available. However, we are not sure whether the program is on a "hold" or has been totally eliminated.

2. I would like to see the F-100 engine diagnostic program rejuvenated and given high priority support. We stand ready to support the Joint Task Force in an effort to increase the maintainability of current and future engines.

JAY T. EDWARDS, Brig Gen, USAF
DCS/Logistics

Cy to: HQ SAC/LG
~~HQ TAC/LG~~
HQ MAC/LG
HQ AFLC/LO
HQ ADCOM/LG
HQ PACAF/LG
HQ ASD/YZ

LG

LGM

EDS

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS TACTICAL AIR COMMAND
LANGLEY AIR FORCE BASE, VIRGINIA 23665

2 MAY 1979

REPLY TO ATTN OF: LGMSP

SUBJECT: Engine Monitoring/Diagnostics

TO: HQ USAF/LEY

1. References:

a. HQ ATC/LG Ltr, 29 Dec 78, Subj: Engine Diagnostics

b. HQ USAFE/LG Ltr, 22 Jan 79, Subj: Engine Diagnostics

2. The above referenced letters recommend the formation of a joint task force to provide coordination and direction for the various on-going engine monitoring/diagnostic programs. We agree that such a force would aid management and continuity and help prevent duplication of effort between systems.

3. We further recommend a briefing be created before formation of the task force. The purpose of this team will be to inform all interested parties of current systems and state-of-the-art technology. Once all parties are educated on current research, the joint task force will be responsible for insuring crossfeed of current information.

4. Much manpower and money have been expended over the past several years on the development of an engine monitoring/diagnostic system. The benefits of on-condition maintenance are attractive, but to be realized a monitoring/diagnostic system is needed in the field.

FOR THE COMMANDER

ALBERT G. ROGERS
Colonel, USAF
DCS/Logistics

Copy to: HQ ADCOM/LG
HQ AFLC/LG
HQ AFSC/LG
HQ ATC/LG
HQ MAC/LG
HQ PACAF/LG
HQ SAC/LG
HQ USAFE/LG
ASD/CV

SEVENTH ANNUAL TRI-SERVICE MEETING

AIRCRAFT ENGINE MONITORING AND DIAGNOSTICS

Arnold Engineering Development Center

December 5-7, 1978

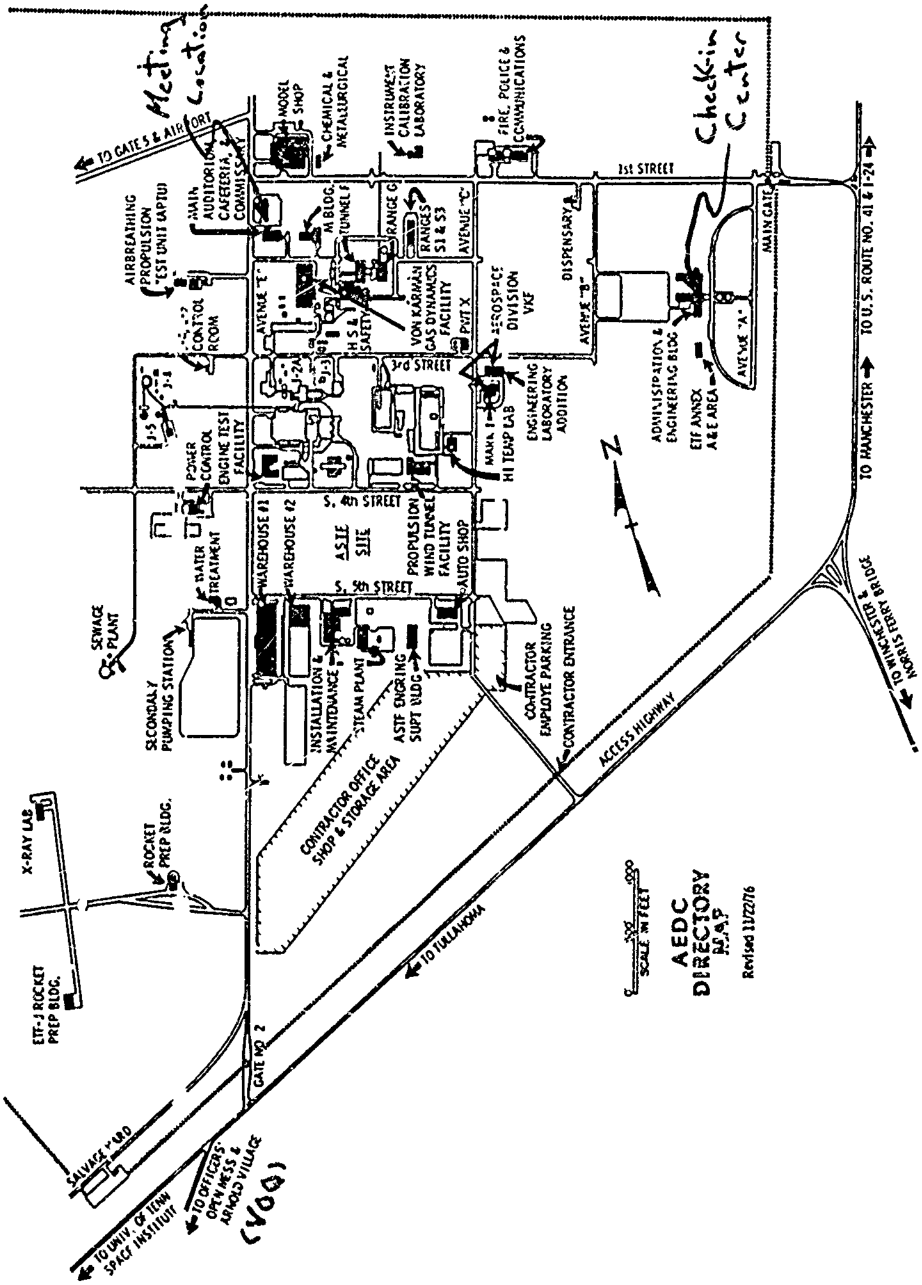
NAME	ADDRESS	TELEPHONE
C. Wade Stevenson	ARO, Inc/ETF/TP Arnold AFS TN 37389	455-2611, X7625
H. S. Hinds, Jr	ARO, Inc/ETF/TP Arnold AFS TN 37389	455-2611, X535
Lt John M. Edens	ASD/ENFPA, WPAFB OH 45433	255-5814
LtCol R. G. Gillis	HQ ATC/LGM Randolph AFB TX 78148	AV 487-2794
Col Jim Streett	HQ SAC/LGME Offutt AFB NE 68113	271-4591
SMS Raymond Strauss	HQ SAC/LGMS Offutt AFB NE 68113	AV 271-5347
John H. Garner	Hq 8AF/LGMS Barksdale AFB LA	781-4877
SSGT Zygmund Jedlecki	55FMS, Offutt AFB NE	294-3964
LtCol Roger A. Crawford	AEDC/DOTA, Arnold AFS TN	AV 882-1520, X7791
Maj William R. McFadden	AEDC/DOTR, Arnold AFS TN	AF 882-1520, X7831
AD1 Charles C. Criminale	Coast Guard, APO Little Rock AR	372-5855
Hans Kohler	AIR-53431C, NAVAIRSYSCOM Wash DC	AV 222-3141
James Evans	NARF, Norfolk VA	AV 690-8[illegible]03
Gerald Schultheis	NARF, North Island, San Diego	AV 951-6623
Robert L. Becker	ASD/YZL, WPAFB OH 45433	AV 785-6676
Edward Whonic	ASD/YZN, WPAFB OH	AV 785-4169
Harold E. Hewgley	AEDC/XRFD, Arnold AFS TN	AV 882-1520, X 7764

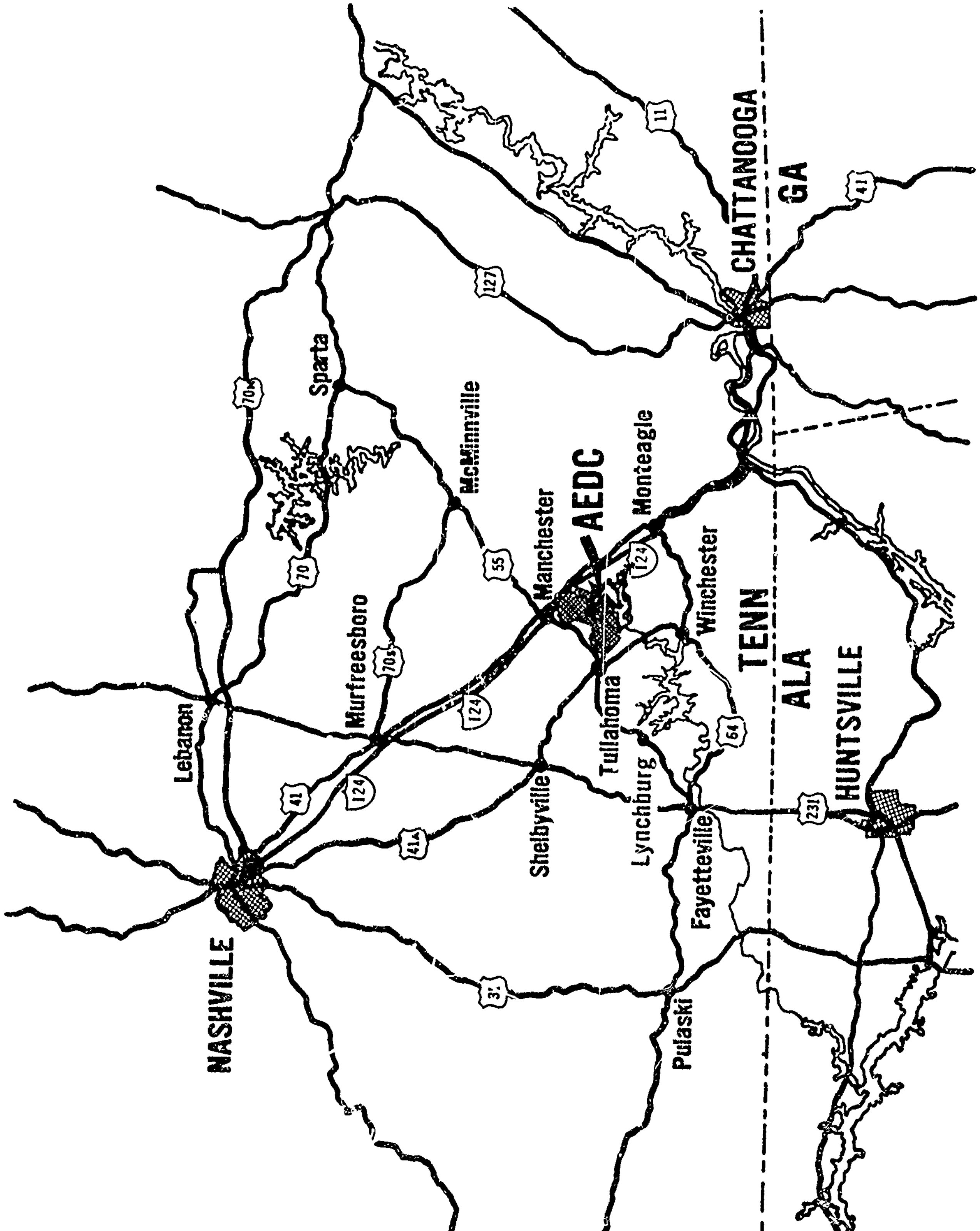
NAME	ADDRESS	TELEPHONE
1Lt Wesley R. Cox	AEDC/XRFX, Arnold AFS TN	AV 882-1520, X7771
John A. O'Malley	Naval Weapons Center China Lake CA	AV 245-7258
A. F. Domal	ARO, Inc/ETF/T2 Arnold AFS TN	455-2611, X611
A. M. Boggan, Jr.	ARO, Inc/ETF/T2 Arnold AFS TN	455-2611, X611
J. P. Honan	ARO, Inc/ETF/T2 Arnold AFS TN	455-2611, X611
Fred N. Till	USAADTA/STEBA-PD-P Ft Rucker AL 36362	AV 558-6112/4418
Robert G. Dodd	US Army Transportation School Attn: ATSP-CD-MS Ft Eustis VA	AV 927-3040/3966
Tom Belrose	US Army Aviation Readiness and Dev. Command St. Louis MO	AV 698-6486
Rich Andres	Parks College of St. Louis U.	775-3700
Tom Harrington	Parks College of St. Louis U.	775-3700
A. F. Pitsenbarger	ASD/ENEGP, WPAFB OH	AV 255-2509
Mike Mills	ASD/ENEGE, WPAFB OH	AV 255-2966
LtCol Cleve Simpson	AFISC/SEFF, Norton AFB CA	AV 876-7001
John Turek	OASD(MRA&L)-WR	AV 284-6052/6053
D. W. White	ARO, Inc/ETF/TP Arnold AFS TN	455-2611, X611
E. C. Wantland	ARO, Inc/ETF/TP Arnold AFS TN	455-2611, X611
E. D. Schultz	Naval Air Rework Facility MCAS, Cherry Point NC	AV 244-4276
Robert H. Wynne	Naval Air Rework Facility Naval Air Station Pensacola FL	AV 922-4311
A. J. Hess	NAVAIRSYSCOM Hq, Wash DC	AV 222-2654

NAME	ADDRESS	TELEPHONE
D. M. Watters	NAVAIRTESTCEN Pax River MD	AV 356-4673
Col Boyd L. Van Horn	HQ TAC/LGM	AV 432-3733
Capt Joel R. Gissendanner	SA-ALC/MMPRR, Kelly AFB TX	AV 945-6001
SMS Ken Pobanz	HQ TAC/LGMS, LAFB VA	AV 432-7571
Douglas R. Barnes	ASD/ENFPJ, WPAFB OH	AV 255-2308
LtCol James L. Pettigrew	ASD/YZEE, WPAFB OH	AV 255-2900
Edward M. Szanca	NASA/Lewis Research Center Cleveland OH	433-4000, X6979
David R. Englund	NASA, Lewis Research Center Cleveland OH	433-4000, X6350
Keith R. Hamilton	AFAPL/TBC, WPAFB OH	AV 785-4061
Alan E. Burwell	AEDC/DOTA, Arnold AFS TN	AV 882-1520, X7791
E. L. Hively	AEDC/DOTR, Arnold AFS TN	AV 882-1520, X7831
Walt Pasela	NAPC PE63, Trenton NJ 08610	AV 443-7262
Lee Doubleday	NASC, Wash DC	AV 222-9125
Col Lowry	HQ MAC/LGM, Scott AFB IL	

Laboratory Complex

(Fenced Area)




NASHVILLE
Lebanon
Murfreesboro
Sparta
McMinnville
Manchester
AEDC
Monteagle
Winchester
Tullahoma
Shelbyville
Lynchburg
Fayetteville
Pulaski
TENN
ALA
HUNTSVILLE
CHATTANOOGA
GA
70N
70
70S
41
41A
124
55
64
231
31
127
11

SUBJECT: Seventh Annual Tri-Service Meeting on Aircraft Engine Monitoring and Diagnostics

DISTRIBUTION:

1. Commander
   US Army Aircraft Development Test Activity
   ATTN: STEBG-PO-O (Mr Fred Till)
2. Director
   Applied Technology Laboratory
   ATTN: DAVDL-EU-MOR (Mr T. House)
3. Research & Technology Laboratories (AVRADCOM)
   ATTN: DAVDL (Mr B. Andre)
4. AEDC/DOTA (Lt Col R. Crawford)
   Arnold AF Station, TN 37389
5. AFAPL/TBC (Mr K. R. Hamilton)
   Wright-Patterson AFB, OH 45433
6. ASD/ENJET (Mr. M. H. Chopin)
   Wright-Patterson AFB, OH 45433
7. TAC/LGMS (MSgt K. W. Pobanz)
   Langley AFB VA 23665
8. 55 FMS/MAD (TSgt C. N. Annette)
   Offutt AFB NE 68113
9. SAC/LGME (Lt Col J. L. Pettigrew)
   Offutt AFB NE 68113
10. 15 AF/LGMS (SMSgt R. R. Hargreaves)
    March AFB CA 92508
11. 17 BMW/MAD (SMSgt D. E. White)
    Beale AFB CA 95903
12. David W. Taylor Naval Ships Research & Development Center/A (Mr W. F. McMillan)
    Code 2781
    Annapolis MD 21402
13. Naval Air Propulsion Test Center
    (Mr Tony Petruccione)
    Trenton NJ 08628
14. NAVAIR Test Center (Code SY-71/Mr J. Martin)
    Patuxent River MD 20670
15. NAVAIR Test Center (Code SA-62/Mr D. Pauling)
    Patuxent River MD 20670
16. NAILSC (ILS-2105/Mr E. A. Schotta)
    Patuxent River MD 20670
17. NAILSC (ILS-431/Mr R. Rosenbrock)
    Patuxent River MD 20670
18. Naval Air Systems Command AQ
    AIR 5363C (JP2/Mr A. Hess)
    Washington DC 20360
19. Naval Air Engineering Center
    Ground Support Equipment Dept/Code 92623 HM
    (Mr. H. C. MacLaughlin)
    Lakehurst NJ 08733

SUBJECT: Seventh Annual Tri-Service Meeting on Aircraft Engine Monitoring and Diagnostics

DISTRIBUTION:

20. San Antonio ALC/MMER (Capt G. Hobart/Mr O. Martinez)
Kelly AFB TX 78241
21. San Antonio ALC/MMEWA (Capt J. M. Vice)
Kelly AFB TX 78241
22. San Antonio ALC/MMEPR (Mr R. S. Saenz)
Kelly AFB TX 78241
23. San Antonio ALC/MMEPJ (Mr A. E. Wright)
Kelly AFB TX 78241
24. HQMAC/XPQ
Scott AFB IL 62225
25. HQMAC/LGMWP
Scott AFB IL 62225
26. FAPL/TBX (Mr L. Oberly)
Wright-Patterson AFB OH 45433
27. AFDSDC/LGMDE (Maj W. T. Dillon)
Gunther AF Station AL 36114
28. AFLC/LOP (Mr B. Richter)
Wright-Patterson AFB OH 45433
29. ATC/LGM
Randolph AFB TX 78148
30. MAC/LGM
Scott AFB IL 62225
31. SAC/LGM
Offutt AFB NE 68113
32. TAC/LGM
Langley AFB VA 23665
33. U. S. Coast Guard
Aircraft Program Office
P. O. Box 6186
Little Rock AR 72216
34. OASD (MR&L)/WR
Room 2B323 Pentagon
Washington DC 20301
35. NASA Lewis Research Center
ATTN: David R. Englund, MS 77-1
21000 Brookpark Rd
Cleveland OH 44135