A-10/TF34 TURBINE ENGINE MONITORING SYSTEM (TEMS)

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SUMMARY

The A-10/TF34 Turbine Engine Monitoring System (TEMS) integrates inflight and ground hardware to sense, signal condition, perform computations and analysis, and record various engine and aircraft information and parametric data for the purpose of fault detection, isolation and trending. Basically, the data are collected, processed and stored by the airborne Electronic Processor Unit (EPU) then transferred through the GO/NO-GO indicating Umbilical Disconnect Unit (UDU) to the Diagnostic Display Unit (DDU) for flight line maintenance use before final transfer to the TEMS ground station peripheral equipment for Jet Engine Intermediate Maintenance (JEIM) shop use, actuarial processing and permanent storage. If flight line display and use of the data is not required, transfer to the ground station may be done with the Data Collection Unit (DCU). TEMS data will be used at the flight line to assess engine GO/NO-GO status, aid in troubleshooting and fault isolation and to perform engine trim. Potential JEIM and depot TEMS information uses include engine troubleshooting and fault isolation, test cell trim and data collection, maintenance programming, parts tracking, spare parts forecasting, and actuarial analysis.

INTRODUCTION

In 1974 the Department of Defense (DOD) adopted the Reliability Centered Maintenance (RCM) concept for all military aircraft systems, consequently requiring restructure of existing aircraft scheduled maintenance programs and establishment of RCM programs for all new aircraft. The DOD RCM concept is based on the commercial airline maintenance decision logic called MSG-2 developed by a committee known as Maintenance Steering Group 2 composed of representatives from the commercial airlines, Air Transportation Association, and Federal Aviation Administration (ref. 1). Basically, RCM is a decision logic process which divides scheduled maintenance requirements into the three basic categories of hard limits, on condition, and condition monitoring, followed by a Maintenance Requirements Analysis that translates the maintenance requirements into specific inspections, limits, tasks, and work packages and produces technical data and instructions for the maintenance of a specific system (ref. 2). The United States Air Force (USAF) incorporated the DOD RCM philosophy into an expanded On Condition Maintenance (OCM) concept, defined as maintenance that allows the condition of the equipment to dictate the need for maintenance or the extent of repair/overhaul required (ref. 3). Successful conversion to full OCM for a complex turbine engine requires the use of monitoring systems such as the A-10/TF34 Turbine Engine Monitoring System

(TEMS) (ref. 4).

The fundamental success of OCM is directly dependent on the ability to adequately perform the tasks dictated by the nature of the three RCM categories, continually assessing the OCM data and updating the RCM analysis by transferring items from one category to any other as necessary. The hard limits category requires parts time and cyclic tracking; on condition generates the need for repetitive inspections or tests; and condition monitoring is greatly enhanced by diagnostic and trending capability. The USAF has always practiced OCM to a certain extent with these functions satisfied by a variety of manual and automatic data acquisition systems. However, recent radical developments in microprocessor technology and data processing have made possible completely automated systems capable of acquiring and processing the vast amounts of data needed to support the OCM of a modern, complex turbine engine (ref. 5).

The TEMS being incorporated into the A-10/TF34 system is designed and built by Northrop Electronics Division and was originally flown on the T-38/J85 combination before being upgraded for the A-10/TF34 application. This paper discusses the operation and interfaces of the A-10/TF34 TEMS hardware focusing primarily upon function, capabilities and limitations. The TEMS data types are defined and the various data acquisition modes are explained. Potential data products are also discussed.

SYMBOLS AND ABBREVIATIONS

ITT - inter turbine temperature

N_F - fan speed

N_G - core speed

PLA - power lever angle

P_{S3} - compressor discharge static pressure

RPM - revolutions per minute

T_{2C} - compressor inlet total temperature

VG - variable geometry

W_F - fuel flow rate

HARDWARE AND INTERFACES

System

The hardware used in the A-10/TF34 TEMS, (Fig. 1), is comprised of inflight and ground equipment to sense, dignal condition, compute and analyze, record and store various aircraft and engine information for fault detection, isolation, diagnostics, trending, and parts tracking (Fig. 2). The basic components are the airborne Electronic Processor Unit (EPU) and the ground used Diagnostic Display Unit (DDU) and Data Collection Unit (DCU). These units are microcomputers that share common components and are based on 8080 microprocessor architecture. The EPU, Umbilical Disconnect Unit (UDU), sensors and signal conditioners, and associated wiring make up the airborne hardware. The ground equipment consists of the DDU, DCU, a printer, Intelligent Disk Unit (IDU), and telephone modem.

In operation, the EPU (Fig. 3) continuously receives and monitors sensor and transducer dignals (Fig. 4) and records and stores a data frame automatically for preselected flight conditions or whenever the pre-established normal limits of a critical parameter are exceeded. Data frames are manually taken and stored upon pilot command through a cockpit data switch or for maintenance record purposes through the DDU (Fig. 5). Data stored in the EPU is retrieved on the ground by either the DDU or DCU through the UDU (Fig. 6), which also provides GO/NO-GO and limit exceedance event indicators. The DDU has real-time display and operation capability and provides maintenance personnel with a display of engine performance parameters, operating conditions, and other information permitting review of routine data and troubleshooting/diagnostic capability at the flight line. Engine trim functions can also be done using the DDU independent of other test equipment. The DCU is essentially the same as the DDU without display capability and both units transfer data to the printer and IDU intthe Jet Engine Intermediate Maintenance (JEIM) shop for permanent storage and further troubleshooting, fault isolation and diagnostic activity as required. Reference 6 contains a complete, detailed description of the hardware and its operation.

Electronic Processor Unit

The EPU provides central administration, execution and regulation of the TEMS. It continuously receives and monitors inputs from aircraft and engine transducers and sensors and performs various functions relating to the signal conditioning, processing and storage of the data. The signal conditioning function converts the sensor signals into scaled direct current values. High impedence isolation between the sensors and conditioners protects on-board instrumentation, allowing the use of existing aircraft instrumentation without affecting the cockpit indicators. After conditioning and multiplexing, the signals are digitized by the Analog to Digital Converter and input to the processor. The processor is the computer portion of the EPU and uses both Random Access Memory (RAM) and Programmable Read-Only Memory (PROM). It constantly monitors and processes the data and, when a maintenance action item has been confirmed, transmits the appropriate information to data storage for ground recovery. The PROM stores the executive routine, equation subroutines, diagnostic logic, signal averaging and instructions. Program constants, calibration data, engine signatures, threshold levels and logic options are stored in the RAM. The RAM also is the working memory and provides temporary data storage for ground retrieval. These memories can be programmed through the DDU to account for engine changes or limit changes without removal of the TEMS hardware. The processor also provides interface control for EPU communications through the UDU to the DDU or DCU.

Umbilical Disconnect Unit

The UDU is mounted in the A-10 nose gear storage compartment for easy access and provides the capability to retrieve data from the EPU, to display aircraft and TEMS status and event mode indicators, and to enter mission configuration information for structural tracking use. EPU data is transferred automatically by connecting the DDU or DCU umbilical to the UDU and depressing the Data Transfer button. Aircraft and TEMS status indicators include red/yellow/green light indicators for NO-GO, Caution, and no limit exceedance events stored in the EPU, respectively. If the NO-GO or Caution indicators are lit, additional information is available in the form of a four digit alphanumeric code, displayed upon command by depressing the status button. This display also indicates TEMS malfunctions.

Diagnostic Display Unit

The DDU is a one-man portable microcomputer unit that communicates with the EPU through the UDU to transfer EPU stored data to the DDU for flightline maintenance use and/or further transfer to the peripheral ground equipment for printout, permanent storage, and processing. The data transfer is simply and expeditiously done and includes automatic data validity checks. The Light Emitting Diode display capability of the DDU provides for flightline review of routine data as well as plane-side troubleshooting and fault isolation when desired, and the performance of engine trim functions independent of other test equipment. The keyboard is used to re-initialize and calibrate the EPU following an engine change or as required by other maintenance action. The DDU microcomputer is the same as that in the EPU and various modules are interchangeable.

Data Collection Unit

The DCU performs the same data transfer function as the DDU but does not have the display capability for flightline data review. The computer and data transfer elements are identical to those in the DDU but the elimination of the display section and part of the power supply results in a much smaller, lighter unit weighing approximately eight pounds that can be easily handcarried whereas the DDU is usually bicycle transported.

Peripheral Ground Equipment

This equipment consists of a Tally T-1612 Printer, a Northrop 094020-301 Intelligent Disk Unit (IDU), and a Vadic VA 3451 Telephone Modem. This equipment provides for permanent hard copy printout for file records and analysis, permanent magnetic floppy disk storage, and transmission of the TEMS data to a central site or more encompassing data system such as the Comprehensive Engine Management System. The IDU has computer logic and programming capability and can provide a variety of printed and plotted data for diagnostics, trending, life usage, and maintenance planning purposes.

DATA ACQUISITION

Automatic Data Collection

During normal flight and ground operation, the various sensor and transducer signals are continuously monitored by the EPU. However, the EPU only records, for ground retrieval, a data frame whenever specific, preprogrammed conditions are satisfied or when commanded by the air or ground crew through the cockpit switch or DDU. There are two classes of preprogrammed, or automatic, data frame recordings: trend data frames and limit exceedance data frames (refs. 7 and 8).

The purpose of the trending data is to obtain operational flight data for comparison with previous records to detect changes in engine performance, collect parts life tracking and usage information, and provide actuarial documentation data. A large supply of data points usually enhances trending accuracy and confidence, but recovery, storage, and analytic capacity limitations restrict the amount of data that can be processed. This has resulted in the present procedure of two trending data categories, each of which may be taken a maximum of once per flight (Fig. 7). The "Liftoff" frame is taken once each flight and consists of the last data scan monitored just before the weight-on-wheels switch indicates liftoff. The "Cruise" frame is taken later in the flight, after satisfying the stability conditions necessary to ensure repeatable data, valid for comparison purposes. Data is taken the first time the stability conditions are met, with no repeats during the sortie. The stability parameters associated with the "Cruise" data frame are elapsed flight time, PLA, N_G, T_{2C}, gun firing, airspeed, altitude, angle of attack and vertical acceleration.

The purpose of the limit exceedance data frames (Fig. 8) is to report abnormal engine operation and to provide supporting data for troubleshooting and fault isolation. The parameters triggering a limit exceedance data frame are ITT overtemp, N_G/N_F overspeed, oil pressure, vibrations, variable geometry schedule, N_G RPM, compressor stall, slow starting, fuel filter by-pass indication, over-g, and fluctuations in oil pressure, N_G, N_F, W_F and P_{S3}.

These parameters were selected from studies of historical failure records, maintenance impact, and detection reliability. When possible, existing USAF Technical Order (T.O.) limits are used for the detection criteria but, in those cases where no T.O. limits exist, reasonable values were determined and assigned through consultation with General Electric Company, the designer and manufacturer of the TF34 engine. In operation, a limit exceedance data frame is recorded upon the initial detection of an out-of-limit parametric value. Data frames are not recorded for a succeeding limit exceedance of that particular parameter but the number of occurrences and total duration of the limit exceedance for that parameter are accumulated and stored for retrieval. Of course, an out-of-limits event by any other parameter will produce a recorded limit exceedance data frame.

Manual Data Collection

Data frames can be manually taken for record purposes by depressing the cockpit switch or upon command through the DDU. The primary purpose of the cockpit switch is to allow the pilot to record data at his discretion to document abnormal or unusual circumstances. A one second depression of the switch produces a data frame. Continuous activation of the switch results in a new data frame every two seconds. Data will be taken by maintenance personnel using the DDU for record purposes during engine trim, engine maintenance or EPU calibration.

DATA

Diagnostic Display Unit

The DDU displayed data is categorized as documentary, measured or computed. This data provides maintenance personnel at the flightline and JEIM shop with engine trim data and troubleshooting, fault isolation, and trending information for performing engine maintenance.

The documentary data includes aircraft and engine serial numbers, flight and record numbers, Julian date, record time, elapsed flight time and flight condition information. The data is primarily for actuarial, record and classification uses.

The measured data consists of the output from each engine sensor. This includes the detected event limit exceedance data and special diagnostic indicators which provide spool differentiation for vibration data, aircraft modes such as slat deployment and out of envelope conditions, and instability information.

The computed data is composed of the results of calculations concerning trim and performance verification. The trim relationships verify airborne and ground fan speed trim, trim margin, variable geometry schedule, and idle trim. The relationships are corrected for bleed air, power extraction, Mach number and droop and, although the airborne checks are valid at part or full power, there are engine minimum speed, maximum pressure, and altitude limitations. The performance relationships have been identified as being effective in measuring specific characteristics through sensitivity analysis pertaining to engine degradation and performance changes.

JEIM Printed Data

All data displayed on the DDU is available by printout in addition to backup data including corrected parameters, calculations, cumulative times, aircraft parameters and fluctuations. Also, information including ITT time above 790°C, ITT time above 810°C, and temperature, fan speed, core speed and compressor static pressure cycles are presented for special parts tracking, life usage, and actuarial functions.

DATA PRODUCTS

Over the period of the past few years, the USAF Aero-Propulsion Laboratory and Systems Control, Inc. (Vt) have been investigating the integration of various data sources, including TEMS, into the USAF maintenance/logistic process (ref. 9) with the objective of developing procedures for reducing and processing raw data elements to provide maintenance decision information to the flight line, JEIM shop, depot, and major command level. The raw data includes maintenance action records, oil analysis results, configuration tracking, and TEMS data. These data are processed into a data file, ranked and sorted, and stored for subsequent access.

A preliminary set of data products have been identified for various user levels. These include summary reports of the operational status of the engine population by base location including such pertinent information as Time Compliance Technical Order completion, spare engine availability, engine and component life data and usage trends. Also, reports for individual engines could be generated with the same type information in addition to maintenance history, oil analysis data and trim and performance trends. Documents prepared specifically for depot and command level use could include a wide variety of actuarial information, parts tracking and forecast usage, fleetwide distribution of maintenance manhours expended for specific failure modes and general fleetwide engine health trends (Fig. 9).

CONCLUDING REMARKS

The A-10/TF34 TEMS hardware and software development is virtually complete and, from the viewpoint of a qualified system, the TEMS is now ready for incorporation to the A-10 force. However, before total retrofit is done, it is necessary to fully develop, validate and establish engine maintenance and management procedures based on TEMS data and to integrate the TEMS data into the mainstream of the USAF maintenance and logistics process. A pilot program is now being initiated with that objective. The program will consist of one full squadron of A-10 aircraft equipped with TEMS and will be done in conjunction with the Comprehensive Engine Management System Increment IV prototype. This will provide for both the development and evaluation of new or modified A-10/TF34 maintenance procedures, capitalizing on TEMS technology, and the engine management data products necessary to provide the basis for a composite, total On Condition Maintenance system for a modern, complex turbine engine.

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USAF TEMS HARDWARE APPROACH

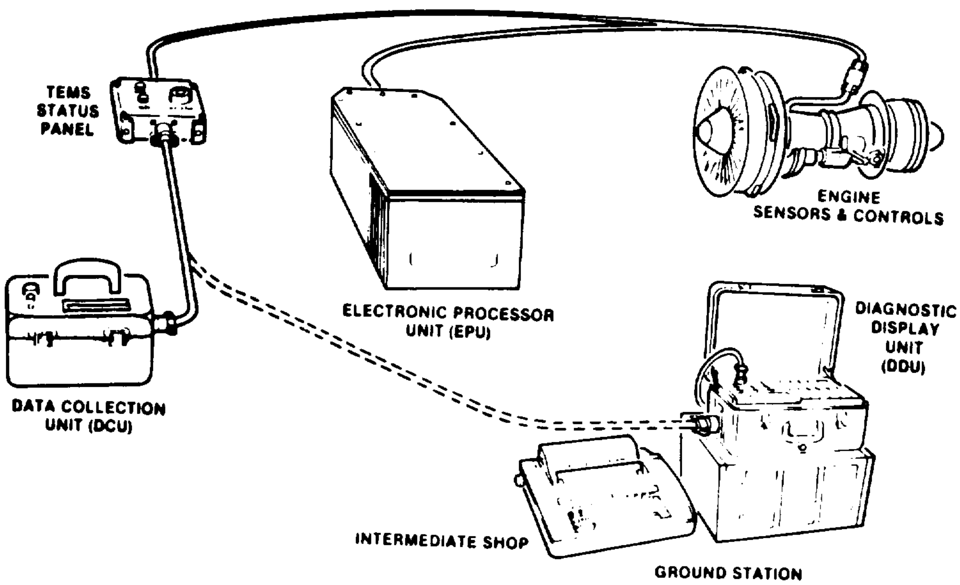

FIGURE 1

A-10/TF34 TEMS

OVERVIEW OF ENGINE MONITORING

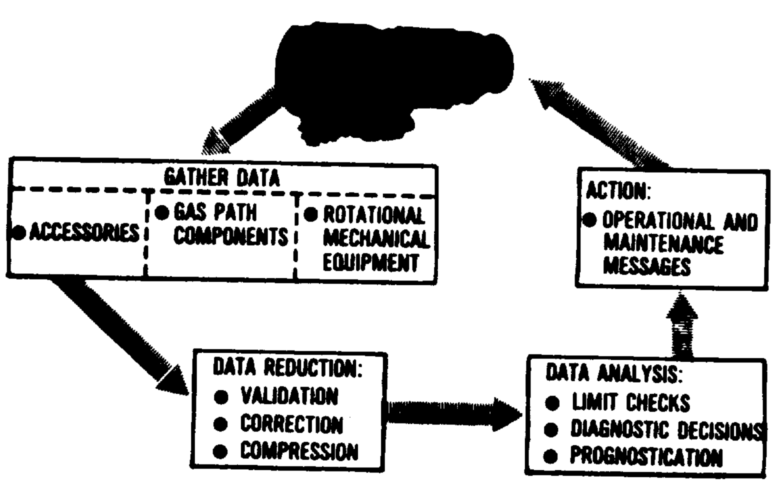

FIGURE 2

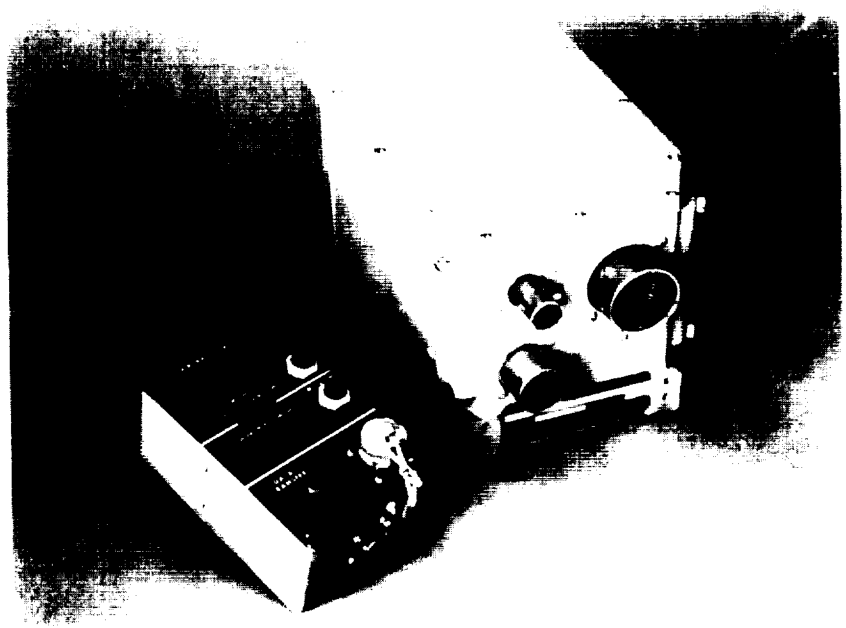

FIGURE 3

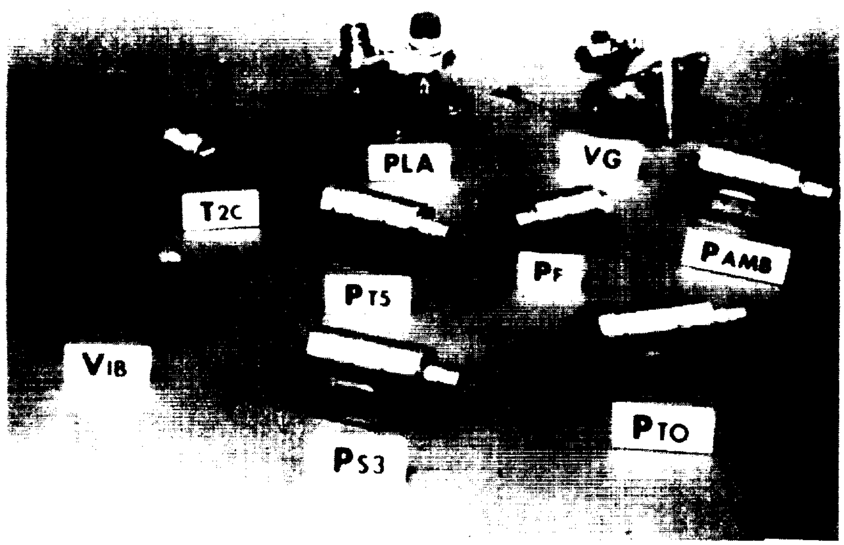

FIGURE 4

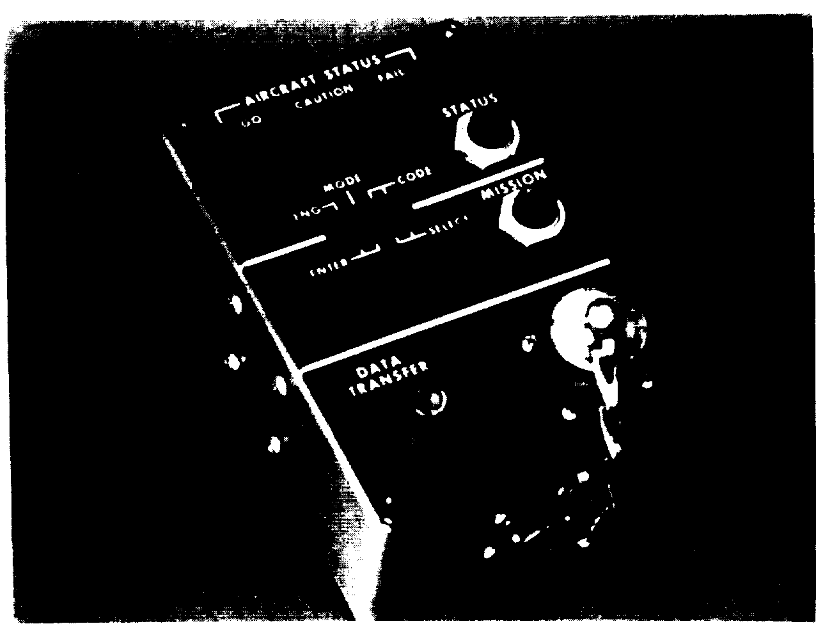
AIRCRAFT STATUS
GO
CAUTION
FAIL
STATUS
MODE
CODE
MISSION
ENTER
SELECT
DATA
TRANSFER

FIGURE 6

AUTOMATIC DATA FRAMES

LIFT OFF	CRUISE
WEIGHT OFF WHEELS	TAKEN NOT LESS THAN 15 MINUTES AFTER LIFTOFF
AIRSPEED > 100 KCAS	NG CORR > 85.4% FOR BOTH ENGINES
NG > 56% FOR ONE OR TWO ENGINES	PLA STABLE ± 1°/2 SEC > 16 SEC
	T_{2C} STABLE ± 1°/2 SEC > 16 SEC
	NO GUNFIRE PRECEEDING 16 SEC
	AIRSPEED 200-300 KCAS
	ALTITUDE > 10,000 FT
	ANGLE OF ATTACK < 15 DEG
	VERTICAL G's 1.5 ± 1.0g > 16 SEC

FIGURE 7

DETECTED EVENT FRAMES

ITT OVERTEMP	ENGINE STALL
NG OVERSPEED	SLOW START
NF OVERSPEED	FUEL FILTER
OIL PRESSURE	OVER G
VIBRATIONS	MAXIMUM ITT SHIFT
FLUCTUATIONS	NF VS ITT ERROR
VG SCHEDULE	NG SPEED ERROR

FIGURE 8

A-10/TF34 TEMS

ANTICIPATED BENEFITS
WHAT CAN ENGINE DIAGNOSTICS SYSTEMS DO FOR USAF?

- REDUCE UNWARRANTED MAINTENANCE
- REDUCE PARTS AND FUEL CONSUMPTION
- INCREASE AIRCRAFT AVAILABILITY
- PROVIDE AUTOMATED ENGINE DATA
- FEED BACK REAL OPERATIONAL DATA FOR FUTURE DEVELOPMENTS

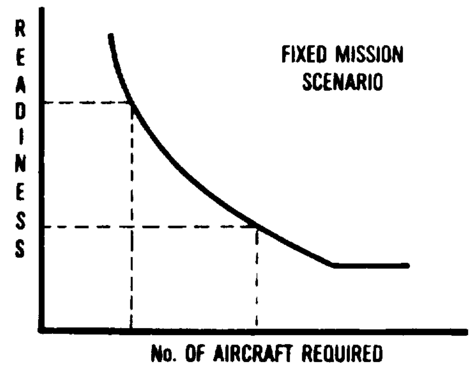

FIGURE 9