Design and Testing of the American Airlines Prototype B-747 AIDS System

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American is currently entering the evaluation phase of its B-747 AIDS (Aircraft Integrated Data System) Program. Prior experience focused attention upon the number of engine parameters to be monitored including parameter accuracy and repeatability. The B-747 prototype system design utilizes increased sampling rates, improved sensors and transducers, and solid state electronics. Analysis of AIDS engine data indicates that the increased sampling rates are required for engine pressure measurements but that the high sampling rates for engine speed are not required. Preliminary results indicate that the increased number of engine parameters will allow isolation of faults to particular engine components such as the high compressor, low turbine, etc. The experience gained to date from this program is portrayed including the status of the B-747 AIDS program objectives. Data utilization is briefly discussed.

Nomenclature

AIDS = aircraft integrated data system
ARINC = Aeronautical Radio Inc.
ATR = Aeronautical Radio Inc. (ARINC) rack sizing designation
DAR = digital AIDS recorder
DFDR = digital flight data recorder
DMU = data management unit
EPR = engine pressure ratio (P_{t7}/P_{t2})
FDAU = flight data acquisition
FDEP = flight data entry panel
Hz = Hertz (cycles/sec)
JT9D = Pratt & Whitney aircraft engine
LR = four minute loop recorder
P.A.M. = pulse amplitude modulated
SAT = static air temperature
TAT = total air temperature (T_{t2})
VSA = variable stator angle
σ_s = standard deviation
N_1 = low compressor speed (rpm)
N_2 = high compressor speed (rpm)
P_{s4} = high compressor discharge static pressure
P_{s5I} = turbine cooling air static pressure
P_{t2} = total air pressure at engine face
P_{t3} = low compressor discharge total pressure
P_{t7} = exhaust gas total pressure
T_{t3} = low compressor discharge total temperature
$T_{t4.5}$ = high compressor discharge total temperature
T_{t6} = exhaust gas temperature
W_f = fuel flow (pph)
δ_{t2} = standard day pressure correction
$(\theta_{t2})^{\frac{1}{2}}$ = standard day temperature correction

Introduction

THE AIDS concept was initiated at American early in the nineteen sixties. The need for an AIDS system was recognized by American as a part of a program aimed at reducing engine maintenance and operating costs. This program is known at American as Condition Monitored Maintenance (CMM) and the program has been expanded to include the B-747 and DC-10 fleets. Part of the CMM program involves the capability to perform on-wing engine condition monitoring. Accomplishment of on-wing engine monitoring required a new electronic monitoring concept. This requirement led to the design of a maintenance recorder system which was installed on the BAC 1-11 aircraft along with a performance recorder and designated by American as "Astrolog".

When American decided to equip its BAC 1-11 airplane fleet with Astrolog,[1] considerable difficulty was encountered in installing the aircraft wiring. To circumvent similar difficulties with the B-747, American purchased AIDS (Aircraft Integrated Data System) wiring provisions from The Boeing Company to be installed during aircraft production.

American Airlines' BAC 1-11 maintenance recorder experience[2] indicated that sensor and system accuracies had to be improved for some of the basic parameters such as total air temperature, total air pressure and engine fuel flow, and that higher sampling rates should be utilized for most of the parameters. The Astrolog program results also indicated that the number of engine parameters should be expanded to improve engine monitoring capability.

Early in 1969, it also became apparent that the number of mandatory crash recorder parameters would be expanded on all future aircraft. Incorporation of the mandatory parameters would require additional electronics. In anticipation that there would be a requirement for an Expanded Crash Recorder System on its new airplanes, American considered the installation of a performance and maintenance recorder as an add-on to the required Expanded Crash Recorder system. (The Expanded Crash Recorder requirement for all future aircraft became law in September of 1970.)

In the fall of 1969, a B-747 Power Plant Monitoring Working Team was created to study the various aspects of engine monitoring, ranging from the simplest cockpit instrument monitoring to the more complex requirements for automated recording systems. This industry team was chaired by The Boeing Company and additionally represented by Pratt & Whitney Aircraft (the engine manufacturer) and six airlines, including American Airlines. The team's charter was to evaluate all measurable engine parameters and establish their usefulness as applied to engine monitoring. This evaluation included an investigation of parameter accuracies.

During the spring of 1970, American evaluated proposals from various prospective manufacturing firms relating to an AIDS installation on a B-747 aircraft. The Hamilton Standard Electronics Division of United Aircraft Corporation was selected as the firm to provide consignment hardware for a one aircraft prototype system. The ensuing maintenance recorder program was based largely upon American's prior BAC 1-11 Astrolog program experience and from recommendations of the AIDS B-747 Power Plant Monitoring Working Team.

During December of 1970, the prototype equipment was installed on B-747 aircraft N9669. The following four

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months were spent in debugging aircraft wiring and associated AIDS equipment problems. In April, 1971, the equipment entered the evaluation phase. The results obtained to date are discussed in this paper.

System Description

The B-747 AIDS Prototype System consists of 3 Flight Data Acquisition Units (FDAU), a Flight Data Entry Panel (FDEP), a Data Management Unit (DMU), a 4-Minute Loop Recorder (LR), a Digital AIDS Recorder (DAR), and a Digital Flight Data Recorder (DFDR) as illustrated in Fig. 1.

Flight Data Acquisition Unit (FDAU)

The Flight Data Aquisition Unit (FDAU) is contained in a ½ ATR box. Three FDAUs are utilized in the system. Each one is capable of receiving inputs from various sensors in different signal forms and levels. Each FDAU performs signal conditioning and multiplexing. The FDAU can accept analog input signals such as synchro signals, AC voltage ratios, certain frequency inputs, DC voltage ratios, variable resistances, potentiometer inputs, and high and low-level DC inputs. The FDAU can also accept digital inputs in accordance with the ARINC 573 specification. The FDAU is equipped with built-in test equipment which automatically determines its status. Four bite test signals are simulated and converted to a corresponding digital number which is then tested during the FDAU subframe synch word generation with a known value. If the simulated signals do not agree with the known values, a bite light indicator comes on showing that a hardware problem exists.

The FDAU is also equipped with a maintenance flag (light) which is operated in the event of a DFDR fault. The FDAUs have an external connector to facilitate utilization of automatic test equipment. Any input parameter to the FDAU can be displayed octally on a test set developed by Hamilton Standard.

Output of each FDAU consists of a serial digital data stream of 64 words per sec. Each word consists of 16 bits. Of the 16 bits, 12 bits are used for data while 2 bits are used for parity and 2 bits are used for synchronization checks. Thus, each FDAU has a serial digital data stream output of 64 words per sec going to the Data Management Unit.

All FDAUs are interchangeable and can either produce an internal clock signal or accept an external clock signal. However, for American's AIDS configuration, FDAU 1 produces the clock/frame synchronization output signal which is utilized by the other 2 FDAUs and the DMU.

FDAU 1 is located in the E-3 main electronics compartment (Fig. 2). Access to this area is either through a door on the underside of the aircraft, through the cargo compartment, or through a removable floor panel located in the first class section of the aircraft. FDAU 2 is readily accessible in the E-11 electronics rack, aft of the pilot. FDAU 3 is located in the E-6 electrical compartment, beneath the forward end of the lower galley floor. Access to this area is gained through a door located on the underside of the aircraft.

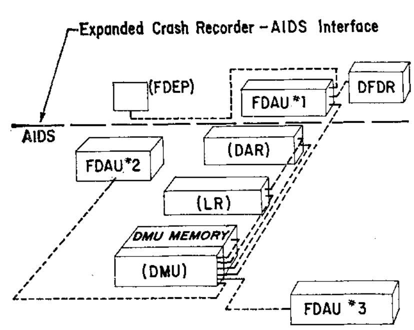

Fig. 1 AIDS Prototype system schematic.

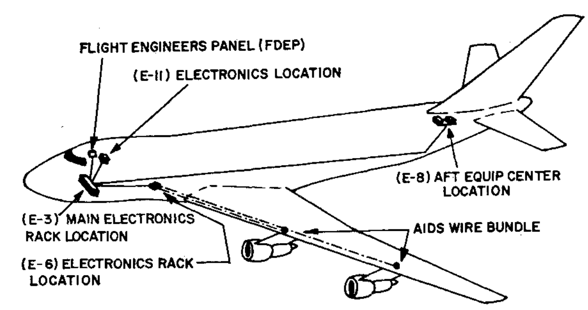

Fig. 2 B-747 AIDS electronic compartment locations.

Data Management Unit (DMU)

The Data Management Unit is contained in two ½ ATR boxes. The DMU accepts, simultaneously, the 3 serial digital data streams coming from the corresponding FDAUs. The DMU performs the function of data management and selection under program control. The prototype DMU serial computer consists of 3 major subsystems; the control unit, the arithmetic unit, and the memory unit. The control unit generates the control signals (micro-commands) which initiate all operations carried on within the computer. The arithmetic unit is the main processing unit of the computer and consists of 2 serial registers (accumulator and accumulator extension). The memory unit consists of 3 sections which are a quick access memory, a scratch pad memory, and a main core store. The scratch pad is recirculating, sequential-access, 4 × 16 words of 16 bits memory. The main core store can handle 1024 words (16 bits each) with random access addressing. The quick access memory consists of 3 one word registers. (The production equipment will have a read only memory unit. Upon finalization of the desired program logic, the equipment will have this program hard wired in and the complete DMU system will be housed in a ½ ATR box.)

The DMU contains special counting circuitry that receives raw N_1 (low compressor) and N_2 (high compressor) speed signals. This circuitry is necessary to produce the desired accuracy for these parameters.

A separate counting circuit is provided for each engine. The counting circuit is shared between N_1 and N_2 for that engine. Because of the large range in speed, a variable sampling rate is utilized to accomplish high sampling at high speed when it is achievable, and a lower sampling rate is utilized at low speed where tachometer frequency characteristics do not permit high sampling rates. The sampling rate is determined by N_1 speed and is under computer control. The resultant digitized engine speed data is multiplexed together with the input data from the FDAUs into a stream of performance data and a stream of maintenance data.

The DMU receives 2 vibration signals (inlet case vertical and diffuser case horizontal) for each engine. These signals are produced by the ENDEVCO Vibration Signal Conditioner. The resultant vibration signals are multiplexed together with bite signals, at a sampling rate of 4/sec. The signal from each pickup is sent through two separate band pass filters. The filters are designed around the fundamental frequencies due to N_1 and N_2. The filter range is 55 Hz ± 5 Hz for N_1 and 123 Hz ± 5 Hz for N_2. The resultant vibration P.A.M. (Pulse Amplitude Modulated) output is fed to two low level DC input channels in parallel on FDAU 1.

The DMU also performs a conditioning function for certain low level DC signals (0 to 50 Mv). These are the intercompressor and high compressor discharge temperatures (T_{t3} and $T_{t4.5}$, respectively) for each engine. The signals are obtained from eight chromel-alumel-thermocouples with chromel-alumel leads. The amplified data leaves the signal conditioner in P.A.M. form and is fed into a FDAU in synchronism with its allocated word slot.

Each engine has three strain gage type pressure transducers (P_{t3}, P_{s4}, and P_{s5I}). These low level signals are routed to a strain gage conditioner in the DMU which provides a calibration measurement to the strain gage amplifier which gives a DC voltage output signal in P.A.M. form. This signal is sent to the respective FDAU in synchronism with its allocated word slot.

Flight Data Entry Panel (FDEP)

The FDEP provides the means to input documentary data to the DFDR (Digital Flight Data Recorder) via the FDAU, as illustrated in Fig. 3. The documentary data are entered via a push-button keyboard located on the data entry panel, illustrated in Fig. 3. Each entry made on the keyboard is displayed on the 6 character, 7 bar display. The first digit entered represents the identification code and appears in the INDENT character display. The remaining digits (up to 5) are then entered from right to left in the value character display. Once an entry is confirmed visually as correct, the data are transmitted to the operating DFDR via the FDAU by depressing the enter button and the displays are extinguished. The sequence is continued until all the required entries are entered. Synchronization of the FDEP is accomplished by receiving clock/sync data in the FDEP from FDAU 1. This enables the FDEP to generate the required timing to insert the documentary data into the allocated time slots of the FDAU 1 data frame.

The FDEP panel also contains an event button, a maintenance history switch, and a maintenance snapshot switch. If the event button is triggered, the previous 2 minutes worth of data prior to event button activation, as well as the following two minutes of maintenance and performance data will be transferred to the performance and maintenance track of the digital AIDS recorder. If the maintenance history switch is engaged, four minutes (two minutes of data before switch activation and two following) of maintenance data will be transferred from the loop recorder to the maintenance track of the DAR. Activation of the maintenance snapshot switch will trigger the DMU to send a four second frame of maintenance data to the maintenance track of the DAR. If the maintenance snapshot switch is engaged continuously, maintenance data will be sent from the DMU to the maintenance track of the DAR until the switch is disengaged.

4-Minute Loop Recorder (LR)

The Loop Recorder is contained in a $\frac{1}{2}$ ATR box and is located in the E-3 electronics compartment. The loop recorder contains a tape cassette which will not be removed unless it is damaged. The tape contains two tracks, one for maintenance data and the other for performance data.

The main function of the loop recorder is to maintain a current history of maintenance and performance data on tape as it is received continuously from the DMU. The old history is maintained for a period of approximately two minutes before that portion of the tape passes under the record head. Therefore, at the initiation of a loop dump it is possible to obtain two minutes worth of data leading up to the trigger point and two minutes or more of data following the event. At initiation of a loop dump command from the DMU, the data contained on the tape are transferred to the Digital AIDS Recorder.

Digital AIDS Recorder (DAR)

The Digital AIDS Recorder is contained in a $\frac{1}{2}$ ATR box. The DAR is located in the AIDS electronics rack in the E-3 main electronics compartment. The tape cassette is loaded through the side of the recorder. (Production units will incorporate tape loading through the front of the unit.)

The DAR tape contains two channels, one for maintenance data and the other for performance data. Each channel has four tracks and can accommodate up to 10 hours of continuous recording. The DAR is controlled by the DMU and can accept single or continuous snapshot data from the DMU or loop dump data from the loop recorder.

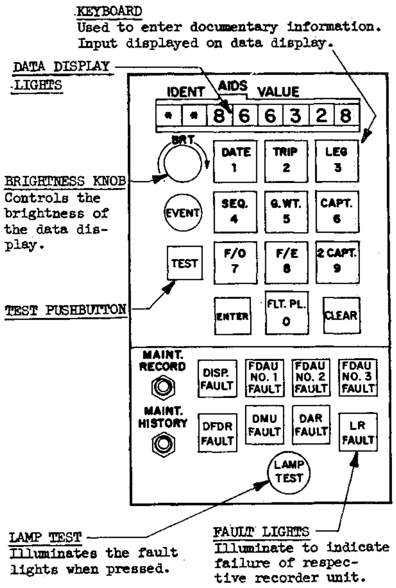

Fig. 3 Flight data entry panel.

During production, the DAR tape cassettes will be removed nightly at flight termination and the data contained on the tape will be transmitted from preselected ground stations to a central processing site.

Engine Parameters

As mentioned in the introduction, the experience gained from the BAC 1-11 Astrolog program and the studies of the B-747 Power Plant Monitoring Team resulted in the list of B-747 maintenance recorder parameters shown in Table 1. The sample rates of the various parameters were determined by considering sensor response, parameter function and relation to other parameters in addition to accuracy requirements. Since engine operation is affected by the temperature and pressure of the air entering the engine, the measurement accuracy of the air entrance temperature and pressure must be taken into consideration, as these parameters are used in engine data correction.

In order to account for the variations in total air temperature and pressure and its effect upon engine operation, all engine data are corrected to a standard baseline defined as sea level standard day conditions. The temperature correction is calculated to be

$$(\theta_{t2})^{1/2} = (TAT/T_{\mathrm{amb}})^{1/2} \qquad (1)$$

where TAT is the total air temperature (absolute). Equation (1) assumes that no inlet losses are present. If inlet losses are not negligible, T_{t2} (air temperature at engine inlet) is utilized in Eq. (1) instead of TAT. T_{amb} is the standard day (sea level) temperature taken to be 519° Rankine. Engine operation is also a function of total air pressure (P_{t2}) and certain engine parameters utilize a correction factor involving P_{t2} as represented by

$$\delta_{t2} = P_{t2}/P_{\mathrm{amb}} \qquad (2)$$

P_{t2} is the total air pressure at the engine inlet (includes inlet loss) resulting from bringing the air to rest from aircraft speed. P_{amb} is the ambient standard day sea level pressure. The following example illustrates the fact that accuracies of the total air pressure and temperature measurements are important in computing engine parameter accuracy requirements.

Table 1 B-747 Maintenance recorder parameter list

Parameters	Sampling Rate	Required Accuracy	Parameters	Sampling Rate	Required Accuracy
Aircraft					
Calibrated Airspeed (CAS)	2 Per Sec	±3 Knots	Exhaust Gas Temp (EGT)	1 Per Sec	±5.5°C
Altitude (Fine)	2 Per Sec	±45 Ft	Turbine Cooling Air Pressure (P_{s5I})	0.25 Per Sec	±1%
Greenwich Mean Time (GMT)	1 Per Sec	±1 Sec			
Static Air Temp (SAT)	0.5 Per Sec	±0.4%	Nacelle Temp	0.25 Per Sec	—
Ram Air Temp (TAT)	0.5 Per Sec	±0.75°C	Variable Stator Angle (Beta)	1 Per Sec	±1°
Mach Number	1 Per Sec	±0.005			
Pneumatic Bleed Duct Pressure	0.25 Per Sec	±0.8 psig	Bleed Flow	1 Per Sec	±7%
			Power Level Angle (PLA)	0.5 Per Sec	±1°
			Oil Quantity	0.25 Per Sec	±0.5 Qt
			Engine Vibration (2 Pickups)	1 Per Sec	—
Engine					
Low Compressor			Start Air Pressure	0.25 Per Sec	±6 psig
Total Discharge Pressure (P_{t3})	2 Per Sec	±1%	Discretes		
Total Discharge Temperature (T_{t3})	1 Per Sec	±1.7°C	Squat Switch	1 Per Sec	—
Speed (N_1)	4 Per Sec	±0.2%	Fuel Heater Switch	0.25 Per Sec	—
			Nacelle Anti-Ice	1 Per Sec	—
High Compressor			High Stage Bleed Valve	1 Per Sec	—
Static Discharge Pressure (P_{s4})	2 Per Sec	±1%	Pylon Valve	1 Per Sec	—
			Pressure Relief	1 Per Sec	—
Total Discharge Temperature ($T_{t4.5}$)	1 Per Sec	±6°C	Wing Anti-Ice Valve	0.25 Per Sec	—
			Pack Valve Position	0.25 Per Sec	—
Speed (N_2)	4 Per Sec	±0.1%			
			Documentary	Entered at beginning of flight	
Oil In Temperature	0.25 Per Sec	±3°C			
Engine Pressure Ratio (EPR)	2 Per Sec	±0.012	Gross Weight		
			Date		
Oil Breather Pressure	0.25 Per Sec	±0.3 psi	Flight Number		
Fuel Flow	2 Per Sec	±45 pph	Flight Leg		
Oil Pressure	0.5 Per Sec	±2 psig	A/C Number		

Data are usually presented utilizing EPR (engine pressure ratio) as the independent variable. Consider Fig. 4 where corrected low compressor speed $N_1/(\theta_{t2})^{1/2}$ is plotted as a function of EPR. If the instrumentation were 100% accurate, the observed engine readings of N_1 would lie on the operating line when corrected by $(\theta_{t2})^{1/2}$. However, every system has sensor, indicator, and associated electronic errors. According to the laws of probability, when quantities are added, each containing an error (Δ transducer, Δ electronics, etc.), their sum contains an error equal to the square root of sum of the squares of the errors of the added quantities. Therefore, for a particular system, over-all system error can be expressed as

$$E_{\text{sum}} = [(\Delta\ \text{transducer})^2 + (\Delta\ \text{electronics})^2 + \cdots (m)^3]^{1/2} \quad (3)$$

Assume that the system error for N_1 as calculated by Eq. (3) was ±0.2%. This error band is illustrated in Fig. 4. However, additional error is introduced because low compressor speed (N_1) is corrected by $(\theta_{t2})^{1/2}$. Now assume that from Eq. (3) the system inaccuracy in measuring total air temp (TAT) amounts to ±2°C and that the value of N_1 under ideal conditions contains no error. A TAT of −20°C with an accuracy of ±2°C and an N_1 of 88% produces an error range in corrected $N_1/(\theta_{t2})^{1/2}$ of ±0.35% as indicated in Fig. 5. It is now apparent that the error due only to TAT introduces ±0.15% more variation in the value of $N_1(\theta_{t2})^{1/2}$ than the error due only to N_1. Therefore, the value of $N_1(\theta_{t2})^{1/2}$ is affected by the accuracies of both N_1 and TAT.

To make the error analysis universal, it is desired to determine the statistical measure of the standard deviation of the variable S where S is defined as

$$S = N_1/(\theta_{t2})^{1/2} \quad (4)$$

with both N_1 and $(\theta_{t2})^{1/2}$ varying. Based upon division of values containing errors[3] the standard deviation (or one sigma) is defined as

$$\sigma S = (A/B)\{(E_{\text{sum}}(A)/A)^2 + [E_{\text{sum}}(B)/B]^2\}^{1/2} \quad (5)$$

Where A represents the mean value of the numerator, B represents the mean value of the denominator, and $E_{\text{sum}}(A)$ and $E_{\text{sum}}(B)$ are the system errors associated with the A and B measurements, respectively. A statistical measure of what a one sigma error for the variable S considering both N_1 and TAT errors is given by

$$\sigma S = \frac{m(N_1)}{m(\theta_{t2})^{1/2}} \left[\left(\frac{1}{m(N_1)} \right)^2 [E_{\text{sum}}(N_1)]^2 + \left(\frac{1}{m(\theta_{t2})^{1/2}} \right)^2 [E_{\text{sum}}(\theta_{t2})^{1/2}]^2 \right]^{1/2} \quad (6)$$

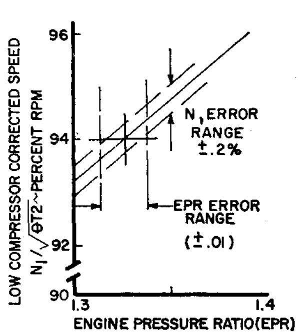

Fig. 4 Error band due to N_1 error.

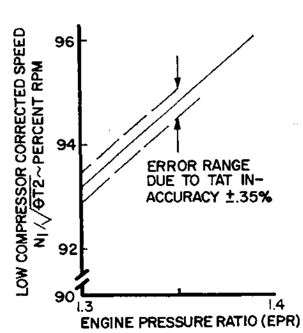

Fig. 5 Error band due to TAT error.

Where $m(\theta_{t2})^{1/2}$ is mean of $(\theta_{t2})^{1/2}$, $m(N_1)$ is mean of N_1,

$$[E_{sum}(N_1)]^2 = [\Delta\, N_1/(\theta_{t2})^{1/2}]^2\text{RPM}$$

$$[E_{sum}(\theta_{t2})^{1/2}]^2 = [\Delta\, N_1/(\theta_{t2})^{1/2}]^2\text{TAT}$$

Therefore, for $[\Delta N_1/(\theta_{t2})^{1/2}]$ RPM system error given by Eq. (3) of $\pm 0.2\%$ and $[\Delta N_1/(\theta_{t2})^{1/2}]$ TAT system error obtained by Eq. (3) of $\pm 0.35\%$ results in a standard deviation of $\sigma S = (0.88/0.9292)[(0.002/0.88)^2 + (0.0035/0.9292)^2]^{1/2} = \pm 0.00417$ or 0.417% for the parameter $N_1(\theta_{t2})^{1/2}$. If the $[\Delta N_1/(\theta_{t2})^{1/2}]$ TAT system error were reduced to $\pm 0.2\%$, the resultant standard deviation for the parameter $N_1/(\theta_{t2})^{1/2}$ would be reduced to $\sigma S = \pm 0.296\%$.

Engine pressure ratio (EPR) is obtained from a ΔP transducer. Assume that the over-all EPR system error is determined to be ± 0.01 EPR units as calculated from Eq. (3) and illustrated in Fig. 4. Since EPR is utilized as the independent variable and has no correction, its resultant standard deviation is $\sigma S = 0.01$. Considering the errors shown in Figs. 4 and 5 and calculating the corresponding one sigma deviation by Eq. (5) has resulted in the one sigma error window illustrated in Fig. 6. The error window illustrated in Fig. 6 will contain 68.3% of all the $N_1(\theta_{t2})^{1/2}$ data for an indicated EPR value of 1.325.

The aforementioned procedure and the experience obtained from the Astrolog program were utilized in establishing required parameter accuracies for the B-747 AIDS engine parameters shown in Table 1.

Figure 7 illustrates the various parameter locations on the JT9D engine. Some of the sensor hardware is difficult to install and installation is economically feasible only during engine buildup or during shop visits. The number of engine parameters, illustrated in Fig. 7, supplemented by the measurement of customer air bleed extraction, will allow a thorough thermodynamic analysis of the engine. More important, the large number of engine parameters selected will allow fault isolation to particular modules or components of the engine. This will facilitate engine maintenance and reduce troubleshooting time. Results of the BAC 1-11 Astrolog program have indicated that the five basic parameters of N_1, N_2, Fuel Flow, Exhaust Gas Temperature, and Engine Pressure Ratio did not suffice to properly isolate or identify faults. If one of the above parameters were lost due to system failure, the resultant parameters would, in most cases, not provide enough information.

To obtain some degree of data repeatability for comparison purposes, the following recording modes were established for the maintenance recorder.

Record Modes (One Four Second Frame)

1) Takeoff—record at 110 knots. 2) Climb—record data at 5,000 ft and 27,000 ft (triggered by pressure altitude). 3) Cruise—sample for 8 minute period—record if altitude does not change more than ±250 ft and Mach number does not change more than ±005. Successive data points triggered every 34 min by GMT clock if altitude does not change more than ±250 ft, otherwise scan for a new stable cruise condition and repeat above process. 4) Landing—Record when SQUAT switch is activated. In addition to the normal record modes, the following recording capability exists.

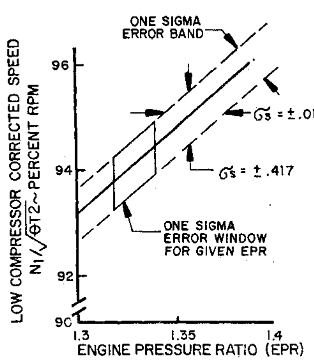

Fig. 6 One sigma error window.

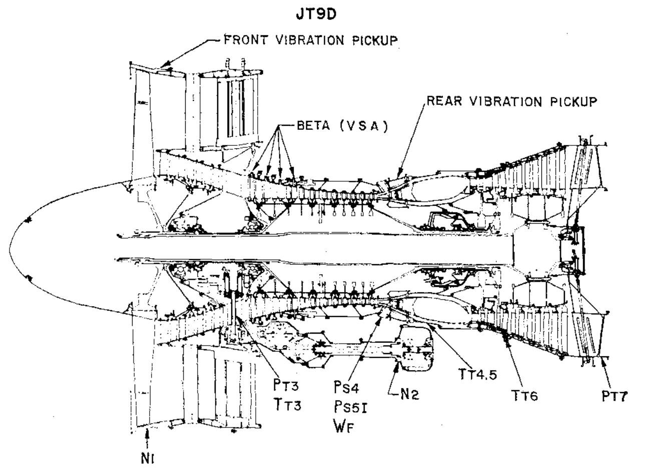

Fig. 7 Engine sensor pickup locations.

Nonstandard Record Modes

1) Maintenance Record—activated by a switch on the Flight Engineer's panel (will record snapshot data as long as engaged). 2) Maintenance History—activated by a switch on the Flight Engineer's panel (will record previous two minutes before switch activation and the following two minutes). 3) Event Pushbutton—same as Maintenance History, but both performance data and maintenance data will be recorded. 4) Automatic Dump of Loop Recorder—will occur if exhaust gas temperature limit or N_2 limit exceeded (4 minutes of data as explained under Maintenance History).

Results to Date

Equipment Problems

The AIDS prototype aircraft entered revenue service during December, 1970. Because of American's route structure, limited aircraft availability resulted in a delayed system checkout. System checkout and verification was also limited by real time data analysis. The B-747 prototype data format is completely different from the BAC 1-11 Astrolog data format. Therefore, the Astrolog data transmission stations could not be utilized to transmit the B-747 AIDS data. Each DAR tape must be mailed to Hamilton Standard for data processing. A period of several days would elapse before the data could be analyzed. Other methods of data transmission are being investigated to eliminate the current time delay encountered.

The prototype system has accumulated over 1100 hr since installation. During this period, the DMU computer memory failed one time due to an electronic problem (chip) associated with one of the memory stacks. Otherwise, the DMU computer has functioned perfectly and does not appear to be affected by aircraft power interruptions. The other problem related to the DMU concerned the failure of three multiplex relay switches in the engine vibration circuitry.

The requirement for a dual channel tape (one channel for maintenance and the other for performance) necessitated a complex recorder design. This requirement applied to both the 4 min loop recorder and to the digital AIDS recorder. The limited amount of time in which to develop the dual channel recorders resulted in design problems which were discovered during operation. Recorder problems have resulted in the loss of a considerable amount of data. The recorders have been redesigned in several areas and data loss has been greatly reduced. A recorder upgrading program is currently in progress.

Problems associated with the three FDAUs involved the failure of three analog to digital converters. The failures occurred in FDAUs occupying the E-6 electronics location, illustrated in Fig. 2. Closer investigation revealed that spilled liquids could run off the galley floor into the E-6 electronic compartment. A shield was installed over this area and no new failures have been noted. Problems also occurred with plastic encased transistors which are being converted to ceramic encased transistors.

Data Analysis

Early data exhibited a cyclic variation of a $\frac{1}{2}$ cycle per sec in all parameters going through the FDAU. Further examination revealed that the cyclic variation originated in the FDAU power supply. A filtering system was installed in the power supply eliminating the cyclic variation. It should be noted that a sampling rate of once per second would not have indicated a hardware problem but would rather indicate a problem with sensor repeatability. System accuracies have not been determined at this time, but data obtained to date was utilized to determine system repeatability for some of the basic gas generator parameters, illustrated in Table 2. As illustrated in Table 2, most of the parameters have a repeatability equivalent or better than the accuracy values illustrated in Table 1. When trending data with a given system, repeatability is an important factor. If a transducer in the aforementioned system is changed, accuracy requirements determine the amount of offset that can be introduced in the trend plots. Therefore, accuracy requirements dictate how close transducers, etc. must be to the actual value whereas repeatability is a measure of the data scatter associated with a given transducer.

Sampling rates, as defined in Table 1, appear to be adequate with the exception of both low and high compressor speeds. Because of the special counting circuitry utilized in the DMU, the compressor speeds have exhibited such repeatability that the sampling rates can be reduced to two per second with little loss of accuracy. During the takeoff mode, the repeatability of low compressor speed (N_1) exceeds the desired accuracy of 0.2 percent by 0.05%. Because of the signal output coming from the low compressor speed pickup, the refinement in electronics is not justified to obtain an improvement of 0.05%.

Table 2 Observed system repeatability

Parameters	Flight Mode		
	Takeoff	Climb	Cruise
Aircraft			
Ram Air Temp (TAT)	±0.7°C	±0.7°C	±0.7°C
Static Air Temp (SAT)	±0.65°C	±0.65°C	±0.65°C
Engine			
Low Compressor			
Total Discharge Pressure (P_{t3})	±0.8%	±0.75%	±0.75%
Total Discharge Temperature (T_{t3})	±3°C	±3°C	±2°C
Speed (N_1)	±0.25%	±0.2%	±0.2%
High Compressor			
Static Discharge Pressure (P_{s4})	±1.0%	±0.95%	±0.95%
Total Discharge Temperature ($T_{t4.5}$)	±4°C	±4°C	±3°C
Speed (N_2)	±0.1%	±0.08%	±0.08%
Engine Pressure Ratio (EPR)	±0.004	±0.004	±0.004
Exhaust Gas Temperature (EGT)	±5°C	±5°C	±3°C
Fuel Flow	±125 pph	±100 pph	±50 pph

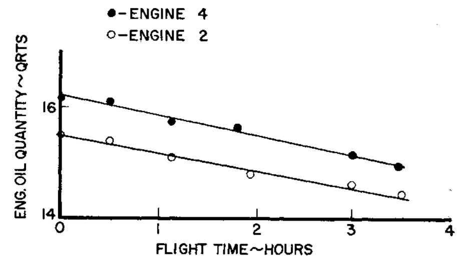

Fig. 8 Engine oil quantity during stabilized cruise.

Comprehensive engine analysis programs have been developed to utilize the output from the parameters illustrated in Table 1. These programs are currently in the check-out phase. An example of a useful parameter is shown in Fig. 8. The engine oil quantity, as measured by a gage in the oil tank for engines 2 and 4, is plotted at various times during stabilized cruise for a particular flight. The slope of the lines indicate the rate of oil consumption for each engine. The comprehensive engine analysis program will calculate engine oil consumption during various flight modes utilizing Greenwich Mean Time and engine oil quantity, and will trend the results. This program will replace the current method of having Line Maintenance teletype the oil added data for each aircraft to Tulsa. Aircraft flight time is currently obtained by manual methods and the results are utilized in the current oil consumption program. This is one of many areas where AIDS will greatly increase system efficiency while reducing over all costs.

The vibration signal from each pickup is processed through two narrow band filters. The filter range for low compressor speed (N_1) is 55 Hz ± 5 Hz and 123 Hz ± 5 Hz for high compressor speed (N_2). The results have been quite promising as indicated by Figs. 9–12. It is interesting to note that, in the case of both engines 2 and 4, the low compressor vibration input is more pronounced in the rear pickup as illustrated in Figs. 10 and 12, whereas the reverse appears true for high compressor vibration. The rear pickup may be better positioned for sensing low compressor vibration than the front pickup. An accelerometer failure on an engine will not limit vibration monitoring to a particular compressor. Each pickup independently appears to provide reasonable vibration data for each spool which provides built-in reliability. Each

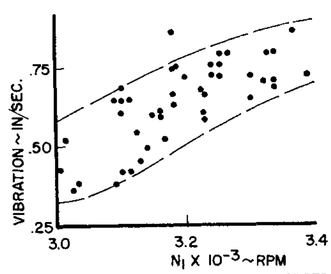

Fig. 9 Engine 4 front vibration pickup (N_1 filter).

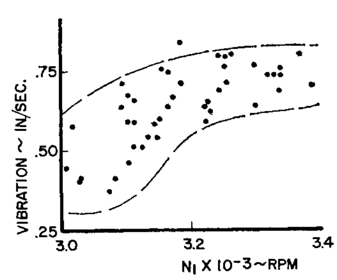

Fig. 10 Engine 4 rear vibration pickup (N_1 filter).

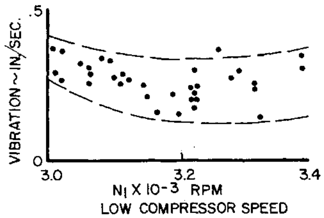

Fig. 11 Engine 2 front vibration pickup (N_1 filter).

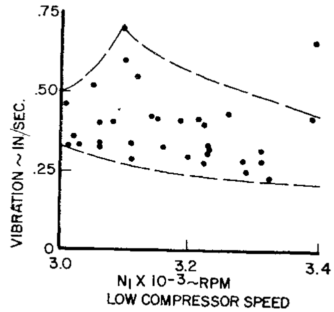

Fig. 12 Engine 2 rear vibration pickup (N_1 filter).

compressor section also exhibits different vibration levels for various speeds as illustrated in Figs. 9–12. Current data indicates that the N_2 filter should operate in the 115 Hz–125 Hz range instead of 118 Hz–128 Hz.

The B-747 AIDS prototype vibration system appears to be a considerable improvement over a single broad band filter. The ultimate vibration system would incorporate a narrow band tracking filter. Utilization of a narrow band tracking filter would allow vibration sampling over the full speed range with a better defined signal. In either case, the resultant data can be utilized for trending purposes. The tracking filter can be utilized as follows. During engine installation, vibration data can be obtained over the whole speed spectrum. From these data an equation can be developed by curve fit techniques which will represent the vibration characteristics of that particular engine at any speed. The vibration characteristics are different for each engine as illustrated by Figs. 9 and 11. Therefore, the vibration levels are always compared to the installed levels at corresponding speeds. Trending the difference will eliminate the variation in basic levels as illustrated in Fig. 9, which are speed dependent.

The JT9D engine has a fitting located on the diffuser case which can be used to indicate the static pressure of the turbine cooling air (P_{s5I}). If excessive seal leakage occurs, the cooling air pressure may drop to an unsatisfactory level, resulting in turbine damage. Figure 13 illustrates the relation of turbine cooling air static pressure and high compressor discharge static pressure with respect to engine pressure ratio. As indicated by Fig. 13, a 5 psi change in P_{s5I} would be detectable on a trend plot. Monitoring of this parameter may indicate turbine cooling problems as the engine ages.

During AIDS hardware testing, an engine start problem was noted on the number 4 engine. During the start sequence, the maintenance recorder was recording data continuously in the manual mode. The data contained on the tape was processed and is represented by the curves labeled "B" in Fig. 14. A

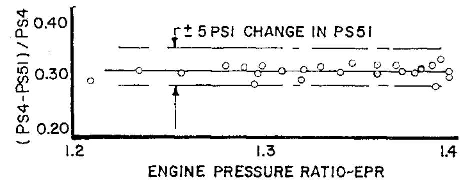

Fig. 13 Engine 4 turbine cooling air differential pressure ratio.

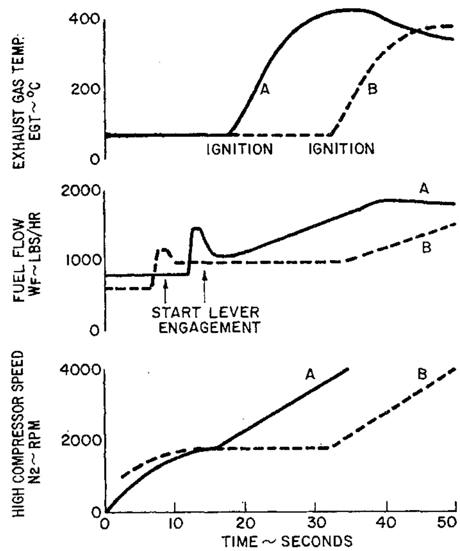

Fig. 14 Engine 4 start data.

normal start was recorded several months earlier and the data are represented by the curves labeled "A". Under normal start conditions, ignition occurs shortly after start lever engagement as illustrated by EGT (curve "A"). The igniter plugs were replaced in this particular engine and no starting complaints have since been noted. This problem could have resulted in a hot start if uncorrected.

Results to date indicate that the B-747 prototype AIDS system will provide the required data and associated accuracy required to support a comprehensive engine monitoring program. In addition to the AIDS hardware, effective data utilization is a must in realizing maximum engine monitoring benefits.

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